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THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

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THE EVOLUTION OF WORLDS

BY A. T. DELURY

(PRESIDENT'S ADDRESS, ANNUAL MEETING, JANUARY 10, 1911).

IN the growth of science it is a striking fact that the thought and strivings of different ages have been very markedly affected, one might say guided or even controlled, by some outstanding prejudice, conviction or method. Thus in the science which our Society fosters, the assumption that the earth is the centre of the universe held the rein on astronomical activity throughout a long period rooted in an antique past and shading significantly into the age we call modern. So also in the newer age of science heralded by Leonardo da Vinci and Bacon, the distinctive mark is the demand that knowledge of the world of nature must be made to rest on observation and experiment. True, observation and experiment were not new as methods, the great legacy of Greek astronomy standing a monument to the true spirit of scientific enquiry, but now they were formulated and insisted upon as the only final basis, and investigation went forward under the new impulse. In our day the great interpretive principle that dominates all science is that implied in the theory of evolution. As in the case of the directing method of

modern science, the idea is not new. The search for beginnings and causes — the *motif* of the great epic of science, the *De Rerum Natura* of Lucretius, he who claims Virgil's noble line,

Felix qui potuit rerum cognoscere causas

—— is as old as the spirit of enquiry, and there is scarcely any science that has not had to consider origins and developments. Yet it was only on the appearance in 1859 of Darwin's great work on organic evolution that the concept assumed its supreme position. It became almost at once the august setting for all science. In all spheres of human thought and interest, facts were now interpreted in terms of it, and conduct regulated in accordance with its supposed dictates. To such an extent, and it may be said with such slight resistance, has the principle of evolution become a condition of our thinking that, in many sciences, it is with difficulty we appreciate the position and understand the language of the leaders of thought of a century ago. It is, as it were, the consort of the observational and experimental method in science, and, like it, cannot be thought of as ceasing to have an increasing value, the growth of scientific knowledge being itself a phase of the all-embracing evolution of things.

In the paper of this evening, we are to consider the more striking evidences of development in that vast extent of time and space which is regarded as the domain of astronomy. Here as in other sciences — if we are not insisting too much on this circumstance — the idea of evolution is not new. Passing over not a few earlier and worthy attempts to account for the present order of things with and about us — our world, and those bodies the moon, the sun, the planets to which our world is "neighbor and near-bred" — we may cite the bold and harmonising hypothesis of Laplace, with which should be associated also the names of Wright and Kant, though their speculations were not known to Laplace. This Nebular Hypothesis or Theory contemplated a vast nebula occupying a space greater than that whose limits are suggested by the orbit of the outermost planet. This nebula, through rotation, and contraction from the emission of heat, under the operation of dynamical laws, was condensed

and moulded into the bodies that make up the solar system as it is to-day. If some bold theorist allowed his imagination to see like origins for individual stars and to assign to them unseen similar planetary families, or to group the stars into ever-widening analogous systems, the children of vast parent nebulæ, it was permitted him by a license kindred to that allowed the poet. The attitude of positive science probably found expression in the words of Comte:

> "It may be admitted that we have a right to speculate, with some hope of success, on the formation of the solar system of which we are a part, for it presents many phenomena perfectly understood and, perhaps, capable of affording decisive testimony in regard to its veritable origin. But what rational basis have we for speculations on the formation of suns themselves? How by reasoning on phenomena can we confirm or invalidate an hypothesis of cosmogony when there is, indeed, not a single phenomenon pertaining thereto, explained or explainable?"

A new era dawned with the discovery by Kirchhoff of the significance of the lines in the solar spectrum, and it is a memorable coincidence that this discovery which was to afford a sure foundation for the theory of stellar evolution was given to the world in the year in which appeared Darwin's immortal work. It had long been known that a ray of sunlight when passed through a prism is resolved into a stream of divergent rays of different colors, producing on a screen a band in which is a succesion of colors such as appears in the rainbow. This band is called the solar spectrum. It had also been known that the band is not continuous, as was at first supposed, but broken by almost countless fine lines parallel to one another and to what we may call the separations of the colors. More recent investigations had shewn that the light from an incandescent body yields a continuous spectrum, while the light from a glowing gas gives a spectrum consisting of one or more bright lines of a color that assigns to them a definite place in the spectrum band — a place characteristic of the particular gas. For example the spectrum of glowing hydrogen is an aggregate made up of a bright line in the red, a bright line in the green and certain others, the spectrum of sodium vapor an aggregate of a double bright line in the yellow and certain others, and the spectrum of iron vapor an aggregate

of a great number of bright lines the most striking being a double line in the green. Kirchhoff found that if the light from an incandescent base or background is made to pass through a glowing gas, which of itself would yield certain bright lines, there appear in the spectrum band dark lines in the places corresponding to the places occupied by the bright lines proper to that gas. Thus the dark lines in the solar spectrum came to admit interpretation and to indicate the presence in the sun's atmosphere of materials such as exist on the earth. Indeed unidentified lines foreshadowed the discovery on the earth of elements not then known. Soon after, Huggins, Angstrom, Rutherfurd, Secchi, Vogel, to mention only a few of the more distinguished workers in this field, devised and perfected means for examining the light from individual stars. Their labors revealed the fact that the remote stars are essentially as our sun, — bodies with an incandescent photosphere surrounded by glowing gases which, affecting the emerging rays of light, disclose the presence in these orbs of elements whose characteristic lines are known, and the existence of which in the sun had already been shewn. Thus, while variety ever presented itself, there could no longer be any doubt of the unity — not the sameness — of constitution of the sun and the distant stars.

In 1864, Huggins succeeded in obtaining the spectrum of a nebula, one of those distant and mysterious appearances that had claimed so much of the time and thought and speculation of Sir William Herschel. I cannot do better than quote from Huggins's account of the discovery — an account written in 1897, in which he quotes from his statement at the time when success waited on his efforts:

"On the evening of August 29, 1864, I directed the telescope for the first time to a planetary nebula in Draco. The reader may now be able to picture to himself, to some extent, the feeling of excited suspense, mingled with a degree of awe, with which after a few moments of hesitation I put my eye to the spectroscope. Was I not about to look into a secret place of creation?

I looked into the spectroscope. No spectrum such as I expected! A single bright line only! At first I suspected some displacement of the prism, and that I was looking at a reflection of the illuminated slit from one of its faces. This

thought was only momentary; then the true interpretation flashed upon me. The light of the nebula was monochromatic, and so, unlike any other light I had as yet subjected to prismatic examination, could not be extended out to form a complete spectrum. After passing through the two prisms it remained concentrated in a single bright line, having a width corresponding to the width of the slit and occupying in the instrument a position at that part of the spectrum to which its light belongs in refrangibility. A little closer looking showed two other bright lines on the side towards the blue, all the three lines being separated by intervals relatively dark.

The riddle of the nebula was solved. The answer, which had come to us in the light itself read: Not an aggregation of stars, but a luminous gas. Stars after the order of our sun, and of the brighter stars, would give a different spectrum: the light of this nebula had clearly been emitted by a luminous gas."

I quote further because of the connection, though it is anticipatory:

"With an excess of caution, at the moment I did not venture to go further than to point out that we had here to do with bodies of an order quite different from that of the stars. Further observations soon convinced me that, though the short span of human life is far too minute relatively to cosmical events for us to expect to see in succession any distinct steps in so august a process, the probability is, indeed, overwhelming in favor of an evolution in the past, and still going on, of the heavenly hosts. A time surely existed when the matter now condensed in into the sun and planets filled the whole space occupied by the solar system, in the condition of a gas, which then appeared as a glowing nebula, after the order it may be of some now existing in the heavens. There remained no room for doubt that the nebulæ, which our telescopes reveal to us, are the early stages of long processions of cosmical events, which correspond broadly to those required by the nebular hypothesis in one or other of its forms."

The nebulæ were thus given a distinct status among the dwellers in outer space. They are tenuous bodies of glowing gas. The remakable line first noted by Huggins is that of an element, peculiar to nebulæ and named nebulium. The other lines indicate the presence of hydrogen and helium.

In the years that followed came great advances in instrumental appliances. The spectroscope was modified, telescopes of greater power constructed, and the powerful aid of photography enlisted in the service of astronomy. The result has been an organised spectroscopic study of a great number of stars, as well as a careful search of the heavens for nebulæ, notably that by Keeler

with the Crossley reflector at the Lick Observatory. It has developed that a great number of the nebulæ, though of an extent and form that differentiate them from stars, yield continuous spectra. A further application of the spectroscope, through the circumstance that an approaching or receding star will show the characteristic lines of the elements displaced to an extent determined by the velocity of approach or recession, has disclosed the fact that many stars are attended by an unseen companion and has thus created an astronomy of the invisible. It is found that, as in the case of visible binaries, the two bodies move round each other in a way in accord with Newton's law of attraction so that with a constitutional unity of the universe we have, at least, one law that seems to be generally valid.

It is in place now to bring together the more essential facts revealed to us by the different methods of investigation: we have

(1) A sun and its attendant planets separated from other celestial objects by distances vast almost beyond comprehension by beings who may speak freely of the ninety or more millions of miles that separate our earth from the sun. This system, independently of the relative motion of its parts, is moving, as a whole, at a great velocity toward the constellation Hercules.

(2) In the vast depth of space is a great wilderness of stars — probably 100,000,000 of magnitude not below 17. These are far from being uniformly distributed throughout the sky, being very markedly condensed towards the Milky Way. The Milky Way itself seems to be a great system with respect to which our solar system occupies a somewhat central position. Round us it seems to coil probably in a widening spiral.

(3) Joint tenants of the deeper space with the stars are the the nebulæ, the number of which estimated by Keeler in his photographic survey is probably 120,000. Comparatively few are gaseous, and these lie near the Milky Way. The stellar nebulæ — those with a distinct nucleus surrounded by nebulous matter — shew a like affinity. The spiral nebulæ constitute the numerous class of nebulæ: they avoid the neighborhood of the Milky

Way and are found with a frequency increasing with the distance from the Milky Way.

We now turn to the evidences of evolution and here the spectroscope must be relied on for assistance. Soon after the spectroscopic examination of the heavenly bodies was entered upon, it became evident that the stars presented a great variety of spectra, so that a classification according to spectra was conceived. A first classification was made by Secchi, and though classes have been multiplied by later workers, the main lines of the bolder classification have been retained. The truth is that the classes in place of being distinct shade into one another and one is free to draw a line at many places. The different types of spectra point to different surface conditions on the stars and the lines retained or rejected, accentuated or rendered feeble, again admit interpretation. The types of stars according to the classification generally received to-day are :

1. The Sirian Stars which are sub-divided into

(*a*) The Orion Stars. These are purely white. Their spectra show helium and hydrogen lines. Many seem to have nebulous appendages.

(*b*) The true Sirian Stars. These are brilliantly white. The spectrum is strong in the ultra-violet region.

2. The Solar Stars. The light is of a golden tinge, as appears in stars like Capella, Aldebaran and Arcturus. There is a decrease in intensity particulary in the ultra-violet, the violet and the blue region of the spectrum. There is every evidence of an increasing condensation and enhanced absorption. Also there is increasing strength of metallic lines.

3. The Antarean Stars. Antares is a typical star of this class. The light is reddish and the spectrum marked by flutings with the sharp edges lying toward the violet. The hydrogen lines are reduced in intensity, and the bands are due to the presence of oxide of titanium, and eight or nine metals can be recognised by their absorption lines.

4. The Carbon Stars. The light reddish, and the spectrum marked by flutings with the sharp edges lying towards the red. Carbon is present. Bright lines are sometimes seen.

How have the circumstances here briefly sketched been interpreted? Let me quote from Hale, one of the most distinguished of living astronomers — cautiously sane in dealing with the speculative:

"Our problem is like that of one who enters a forest of oaks, and desires to learn through what stages the trees have passed in reaching their present condition. He cannot wait long enough to see a single tree go through its cycle of change. But on the ground he may find acorns, some unbroken and some sprouting, others have given rise to rapidly growing shoots, and saplings are at hand to show the next stage of growth. From saplings to trees is an easy step. Then may be found, in the form of dead limbs and branches, the first evidences of decay; reaching its full in fallen trunks, where the hard wood is wasting to powder.

Scattered over the heavens are millions of stars, each representing a certain degree of development. The cloud form of the nebulæ tells us of stellar origins, the white, yellow and red stars illustrate the rise and decline of stellar life; and the earth itself affords a picture of what may remain after light and heat have been extinguished."

This view of the evolution of worlds, so briefly and simply, yet effectively stated, is accepted very generally by those competent to entertain an opinion in this regard. Nebulæ — some tenuous throughout, others, as the great nebula in Orion, showing well marked nuclei of condensation, others grasping in their vast folds, as in the Pleiades, and regions of the Milky Way, whole systems of well defined stars, all of an extent vast when compared with our solar space — disclose an evolutionary movement into stars. Stars of the earlier types, with their freer light and low specific gravity, confirm their affinity to the nebulæ. Continued condensation builds up stronger atmospheres that tell their story in the spectral lines, until in the Antarean and Carbon Stars the last period of luminous stellar life is reached. In the great advance one cannot demand uniformity of development; rather, on the other hand, diversity of process, often difficult to explain. Yet no longer can the fact of progressive development along certain broad lines be questioned.

The great facts of evolution in regard to the general scheme of things being admitted, the question as to the details of the process in a single system naturally arises, and naturally too we turn to the system which we can examine at closest range, the solar system of which we are a part. No longer do we find a large measure of agreement as to the lines of progress. Certain bolder features call for a quite general assent, but divergent theories and assumptions soon appear, and where assumptions may be so varied, and final tests of theories can so seldom be made, there is a rich field for conflicting explanations and controvery. An examination of the various proferred theories, particularly when one has to give some account of them, may well call up the opening lines of the great poem of Dante, which itself had as setting the universe as conceived at the time:

"In the middle of the journey of our life, I (came to) myself in a dark wood [where] the straight way was lost.

Oh! how hard a thing it is to tell what a wild and rough and stubborn wood this was, which in my thought renews the fear!

So bitter is it, that scarcely more is death, but to treat of the good that I there found, I will relate the other things that I discerned."

Fortunately the "good" and the "other things" here call for only brief treatment. First let us consider in mere outline the Nebular Theory of Laplace, and it may be best to follow his own account:

"To arrive at the cause of the primitive motions of the planetary system we have the following phenomena: the motions of the planets in the same sense and almost in the same plane; the motions of the satellites in the same sense as the planets; the motion of rotation of these different bodies and of the sun in the same sense as the movement of revolution, and in planes only slightly different; the almost circular form of the orbits of the planets and satellites.

Let us see if it is possible to rise to their veritable cause.

Whatever its nature, since it produced or directed the movements of the planets it must have embraced all these bodies, and in view of the great distances which separate them it must have been a fluid of immense extent. To have given to them a movement almost circular and in the same sense about the sun, this fluid must have surrounded the sun as an atmosphere. The consideration of the planetary motions leads us to think that in virtue of an excessive heat, the atmos-

phere of the sun originally extended beyond the orbits of all the planets and that it retreated by successive steps to its present limits.

In its primitive state, as we have supposed it, the sun resembled those nebulæ which the telescope reveals to us as composed of a nucleus more or less brilliant, surrounded by a nebulosity which in condensing to the surface of the nucleus transforms it into star. If by analogy we conceive all the stars as formed in this way, we may imagine their former state of nebulosity, preceded itself by other states in which the nebulous matter was more and more diffuse, the nucleus being less and less luminous. Thus, retreating as far as possible, we arrive at a nebulosity so diffuse as not to reveal its existance."

Then describing how under condensation and an increased rotation there should be abandoned, at successive stages, rings of vapor, he goes on to say that

"If all the molecules of a ring of vapor continued to condense without separating, they would form in time a liquid or a solid ring, but the regularity which this formation demands in all the parts of the ring and during the cooling process must have rendered this phenomenon extremely rare. The solar system offers but one example of it,—the rings of Saturn. Almost always each ring of vapors must have become broken into several masses, which, actuated with velocities showing only slight differences, have continued to revolve, at the same distance, round the sun. These masses must have assumed a spherical form with a movement of rotation in the sense of their revolution, since the interior molecules had a lower velocity than those near the outer edge of the mass. But if one had been sufficiently powerful to reunite successively by its attraction all the others round its centre, the ring of vapors would have been transformed into a spheroidal mass of vapors revolving about the sun, with a rotation in the sense of its revolution."

We need not follow the details of the process further, but Laplace goes on to say that all of the phenomena first cited

"follow from the hypothesis which we propose, and give to it a high probability:"

and states further that

"If the solar system had been formed with a perfect regularity, the orbits of the bodies which compose it would have been circles whose planes, as well as those of the different equators and rings, would coincide with the plane of the solar equator. But one would suppose that the variations beyond number, which must have existed in the temperature, and the density of the different parts of these great masses produced the eccentricities of their orbits, and the deviations in their motions from the plane of the equator."

The hypothesis was very generally accepted and has continued to hold an outstanding position among the theories that have been offered as, at least, partial substitutes. Later investigations and discoveries have reduced the simplicity of arrangement and condition that was present to Laplace's mind. Planets have been added, Mars has been found to have two satellites, and generous additions of moons have been made to other planets. The two outermost planets rotate in a retrograde sense carrying in that sense with them their attendant moons. The outermost moons of Saturn and Jupiter revolve about their parent planets in a retrograde sense, and at a quite abnormal distance. The rings of Saturn, shown to consist of discrete masses, have their inner half rotating about the planet in a time shorter than its period of revolution, and the same is true of the inner moon of Mars. Both Babinet and Moulton have pointed out difficulties in the dynamical theory that are more than grave. Modern physics questioned the possibility of a nebula, of the vast size we know them to be, existing in a state of gas glowing at a high temperature, and retaining its frontier. The labors of Roche, supplied an explanation of certain of these irregularities. Darwin showed in his remarkable memoirs on "Tidal Friction" that in the tides there is an auxiliary agency that would account for certain other departures from regularity. Ball and others suppose the primitive nebula to have been non-gaseous and to have come gradually to a high temperature through contraction and condensation into different centres. More recent physics allows the existence of nebulæ of low temperatures as a whole, yet with particles here and there of high temperatures yielding the gaseous spectrum. The aggregate result is that to-day a majority of those competent to judge, retain the main features of the Laplacian hypothesis. Thus, Darwin writing in 1899, says:

"There is good reason for believing that the Nebular Hypothesis presents a true statement in outline of the origin of the solar system."

and Sir Robert Ball, writing in 1909,

"That the earth's beginning has been substantially in accordance with the great Nebular Theory is, I believe, now very generally admitted."

But many modifications of the hypothesis, and not a few theories that reject it, have been offered.

Chamberlin, the distinguished geologist, and Moulton, to whom reference has already been made, reflecting on the difficulties standing in the way of Laplace's theory, struck by the fact that the spiral nebulæ constitute by far the most numerous class of nebulæ, considering also certain geological demands, proposed quite a new theory. A sun passing near to a second sun excites in it, through attraction, an extraordinary tidal condition. Great protuberances on each side, in the direction of the disturbing sun ensue. Parts of those protuberances revolving in train about the parent sun condense and attract to them the smaller cooled parts of the protuberances that are to hand, as well as such other matter as may be gathered in from the space through which the system is passing. The disturbed sun in its early career presents the appearance of the spiral nebula. This theory has met with a large measure of approval rather than acceptance. Connected with it are serious difficulties. Thus, Hale pertinently asks "How can these small bodies — the projected matter from the sun — remain brilliantly luminous for many years? and, why do we not discover incipient spirals giving a bright spectrum?" If it be answered that large and small are merely relative, then may we not say with Ball, conjecturally, that the spiral nebulæ, — vast as under any consideration they must be — may be of an order quite different from what we have supposed, generators not of a stellar but of a galactic system.

Quite recently there has appeared the second volume of the great work of See, on the "Evolution of Stellar Systems." The author points out numerous objections to the theory of Chamberlin and Moulton, insisting that if the theory were true we should have the following consequences:

(1) Spiral nebulæ would be abundant where the stars are

densest, as in the clusters and the Milky Way; because their close approaches would, on the average, be most frequent.

(2) Spiral nebulæ would be especially abundant in the densest masses of stars such as the globular clusters, because close approaches would there attain maximum frequency.

(3) The spiral nebulæ should nearly always occur in pairs, for the disruption of one of two passing stars would generally imply the disruption of the other.

These consequences are not actual, and since the theory of probability of collision or approach is extremely slight, quite too slight to account for the hundreds of thousands of spiral nebulæ, See holds the theory to be untenable. As a further argument against it, though he affirms it to be unnecessary to thrice slay the slain, he quotes the objection of Miss Clerke that,

> "The events contemplated in it are on a small scale by comparison with the grandiose dimensions which we must ascribe to spiral nebulæ."

Of the theory proposed by See, only the merest hint can be given. It is called the Capture Theory. Nebulæ are formed by the agglomeration of fine dust expelled from the stars by the repulsion or pressure of their light and by the electric forces. This dust collects and begins to condense and develop into a cosmical system. In the nebula a vast number of meteorites are formed by the precipitation of ions, whence small globes develope, and as the mass is widely scattered, each small globe has about it a sphere of influence within which its attraction is supreme. The result is that the small globes grow by accretion, and in time very much augment their masses. This again is a process of capture and consists in augmenting the masses of the bodies forming in a nebula, and in decreasing their number correspondingly. Thus are generated planets and moons. The acceleration of the earth's rotation is due to the fall of cosmical dust, and the resistance of the nebular medium tends to make the orbits approach a circular form.

Such, in merest outline is the main part of See's theory, and Laplace is thrust unceremoniously out of court with Chamberlin and Moulton.

Many variants of the earlier theories or hypotheses might well be touched upon, but time will not permit. I mention only in this connection that in a work, just from the press, *Essai de Cosmogonie Tourbillonaire*, M. Belot would seem to work out a dualistic theory based on a combination of the gravitational principles of Newton and the vortices of Descartes.

In the various hypotheses that have been considered, there must, one will admit, be some measure of the actual. May it not be that they seek to be too exclusive? May it not also be that in developing a criticism of a theory we may strain too far a so-called physical law, which may be a good working principle for such ranges as offer themselves in this small world that we inhabit. For example, in the temperatures and pressures that must exist in such a body as the sun, may it not be that our ordinary chemistry and physics are alien or inadequate? Thus, geometry on a small part of the surface of a large sphere is, within the limits of measurement, the geometry of the plane; but when we move out into the ampler regions of the spherical surface we need a new geometry. Indeed, the history of science is eloquent of warning against a dogmatism founded on a limited experience. Not many years ago it was generally assumed that the bright-line gaseous spectrum could come only from a molecule agitated under a high temperature, and the difficulty of conceiving a vast tenuous nebula continuing in a state of high temperature was very great. Now we know that under an electric strain, which does not imply a high temperature, the electrons in the component atoms excite in the ether the vibrations that characterise the element which is their source. Recent years have seen striking developments in physical theories,—developments that menace the classical mechanics, with its theory of energy that was and still is equal to the task of explaining all ordinary phenomena. What readjustment of theories may be necessary no one can as yet say, but it may be that in it a

critique for our many and conflicting cosmic theories may be found.

However, this may be, enough has been said to show that in the "sounding labor-house vast" worlds are in the making along the lines of an all-embracing evolution, the main features of which we grasp, the final details of which we can never know. With Sir Edwin Arnold, schooled in the eastern philosophy to an appreciation of the vast rôle of mystery, we may ask and say:

> "Shall any gazer see with mortal eyes?
> Or any searcher know by mortal mind?
> Veil after veil will rise — but there must be
> Veil upon veil behind."

THE ORBIT OF ν ORIONIS

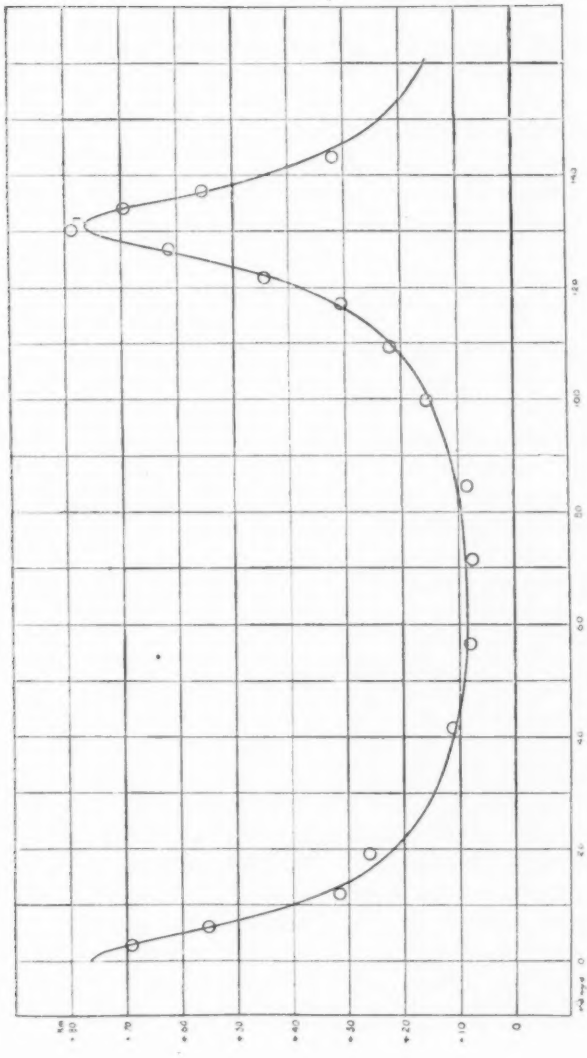
By W. E. Harper

THE spectroscopic binary ν Orionis ($\alpha = 6^h\ 02^m$, $\delta = +14^\circ\ 47'$, photographic magnitude about 4·2) was discovered* by Frost and Adams in 1903. The range in velocity of their three plates is approximately 70 km., which is in fact about the total range for the star. Their first observation was made at a fortunate time, it falling on the crest of the velocity curve which rises rapidly to a high positive value and falls again as rapidly. On this account this observation has been of material assistance in getting a more accurate value of the period than could be obtained from our own observations.

Work was commenced on the star here November 11, 1907, and from that time to December 30, 1910, one hundred and nineteen plates were secured. The first season's work gave the general form of the curve, and during the three succeeding seasons efforts were made to obtain a full series of observations around periastron where the curve, as previously mentioned, changes so rapidly. In this we have been only partially successful, as cloudy weather at each return to periastron prevented our obtaining all the observations desired. Nevertheless quite a number of reliable plates have been secured for this part of the curve and the determination of the orbit has accordingly been proceeded with.

The spectrum is of type B_2 and has numerous lines suitable for measurement. The hydrogen lines H_ζ, H_γ, H_δ and H_ϵ appear in the range of spectrum measured, but the latter was scarcely

* *A. J.*, vol. xviii., p. 386, 1903.



VELOCITY CURVE OF ν ORIONIS

ever measured owing to the close proximity of the *H* line of calcium and consequent overlapping. The helium series λλ 4713, 4471, 4388, 4143, 4121, 4026 and 4009 are all measurable and these, excepting the first and last, were among the most frequently used. The magnesium λ 4481 and the calcium *K'* λ 3933 are not so intense as either the helium or hydrogen series and do not appear in many of the spectra.

In view of the fact that a number of binaries have recently been discovered in which the calcium lines *H* and *K'* give different velocities to the other lines it may be noted here that this is not the case with ν Orionis; the velocites of the *K'* line agree with those of the other lines. Another good line is the carbon λ 4267. These were the lines most frequently measured but additional lines in a number of cases have been seen, and where these have been measured the resulting velocities were always in agreement with the lines most commonly used. Among these additional lines may be mentioned: λλ 4572, 4563, 4549, 4528, 4452, 4383, 4325, 4308, 4233, 4131 and 4128. There are also indications of the second series of hydrogen.

On the first one hundred plates all the lines that were at all measurable were used. When the results were plotted with the the provisional period of 131·4 days there were many little irregularities in the curve; its appearance was that of a wavy line. As no indications of a second spectrum had been detected, even though a fine-grained plate had been used at the time of maximum positive velocity, it was difficult to account for this. It was thought that a possible cause might exist in the selection of lines varying from one plate to another. To decide this point and incidentally see if the wave-lengths used needed any arbitrary correction a table was constructed of the residuals for each line from the mean of the plate. The result is contained in the accompanying table. Besides the twelve lines here listed there were various others which did not occur frequently enough to make mention of. The lines are arranged in order of frequency of measurement, the total number of plates being 100.

LINES MEASURED IN ν ORIONIS

λ	Number of Times Measured	Average Residual	Corresponding Correction to Wave-length
4340·634	97	−1·39 km.	+·020 t. m.
4388·100	94	0·43 "	+·007 "
4471·670	94	+1·51 "	·022 "
4143·928	86	0·03 "	·000 "
4026·352	75	+1·67 "	·022 "
4267·301	68	2·45 "	+·035 "
4121·016	63	−0·11 "	+·002 "
4481·490	62	+1·95 "	·029 "
4101·899	56	+0·99 "	−·014 "
4713·308	20	1·48 "	
4861·527	19	+3·70 "	
3933·825	13	+1·40 "	

No corrections to wave-length are given for the last three as the observations were deemed too few in number, and, furthermore, the ends of the spectrum may not always have been in focus, thereby causing these residuals to be abnormal. The residuals in the above table are, in general, small relative to the probable error of a plate, and while somewhat better accordance among the different lines on a plate would be secured by adopting an arbitrary set of wave-lengths based on the corrections, yet none of the residuals are so abnormal as to warrant such a procedure and accordingly the normal values have been retained. In subsequent measuring the first nine lines of the table were the only ones used, and the other hundred plates were recomputed, using these lines alone so that the results ought, at least from a consideration of wave-length, to be consistent.

Plates from 1140 to 2257 were made with the single-prism spectrograph IL as first constructed, the dispersion at H_γ being 30·2 tenth-metres per millimetre. The balance were made with the new single-prism instrument, designated I, whose dispersion is 33·4 tenth-metres per millimetre at the same region. Plates 3369, 3847, 3865 and 3890 were made on Seed 23 plates, the remainder on Seed 27 emulsion. The four Seed 23 plates were made at times of high positive velocity to see if any trace of the second spectrum could be detected. No indications of such were seen.

Two plates have been omitted in the discussion, one, 2098, which gives a residual of 25 km. where the curve is well-defined in the flat part. This is probably owing to some instrumental error. The other case is that of plate 1315 which was taken immediately following plate 1314 under almost identical conditions and yet gives a decidedly greater positive velocity. The plate is somewhat underexposed, but there would seem to be some additional cause for the great difference in velocity, and as these observations occur around periastron, this was one reason why a continuous series of plates at this phase was much wished for. The intention is to make more plates next season at this critical place in the curve. The remaining 117 plates form the basis of this discussion and the data regarding them is contained in the table following. The phases are reckoned from the periastron finally accepted, Julian Date 2,417,975·16, and the residuals are scaled to about ± 0·2 km. from the curve representing the final elements.

MEASURES OF *v* ORIONIS

Plate	Julian Date	Phase	Velocity	Weight	Observer	O-C
1140	2,417,891·93	48·03	+ 5·0	4	H	− 4·4
1160	903·78	59·88	+ 12·0	3	P	+ 3·4
1184	914·92	71·02	+ 4·5	5	P	− 4·3
1185	914·95	71·05	+ 3·9	5	P	− 4·9
1197	938·73	94·83	+ 12·6	6	P	− 0·3
1198	938·75	94·85	+ 15·2	4	P	+ 2·3
1217	944·73	100·83	+ 18·1	6	P	+ 2·7
1223	954·81	110·91	+ 23·8	5	P	+ 1·1
1224	954·84	110·94	+ 30·6	5	P	+ 7·9
1229	955·84	111·94	+ 28·1	3	H	+ 3·3
1235	957·54	113·64	+ 22·5	4	H	− 1·5
1250	961·71	117·81	+ 37·6	6	P	+ 4·8
1251	961·73	117·83	+ 30·5	3	H	+ 3·7
1261	963·78	119·88	+ 37·4	5	P	0·0
1273	965·59	121·69	+ 41·4	6	P	− 1·3
1282	968·58	124·68	+ 52·6	4	P	− 1·6
1302	970·65	126·75	+ 51·0	7	H	− 11·5
1303	970·67	126·77	+ 60·4	6	H	− 2·1
1314	975·62	0·46	+ 73·5	4	H	− 2·7
1320	980·70	5·54	+ 50·1	7	P	+ 0·5
1325	989·65	14·49	+ 29·5	6	H	+ 0·7
1326	989·66	14·50	+ 14·7	3	H	− 15·5
1335	992·57	17·41	+ 22·5	5	P	− 2·1
1337	993·69	18·53	+ 30·8	7	P	+ 7·6

Plate	Julian Date	Phase	Velocity	Weight	Observer	O − C
1348	2 417,994·72	19·50	+28·5	6	P	+ 6·2
1352	996·62	21·46	+26·7	6	P	+ 6·4
1377	8,005·68	30·52	+21·4	4	H	+ 7·0
1385	010·68	35·52	+12·2	6	P	− 0·1
1396	017·53	42·37	+14·3	6	P	+ 3·8
1485	047·59	72·40	+16·9	2	H	+ 8·1
1497	049·53	74·37	+10·3	6	P	+ 1·4
1503	054·55	79·39	0·3	2	H	9·6
1910	217·94	111·52	+20·	3·5	C	− 3·4
1943	234·90	128·54	+63·	1·5	H	− 7·5
2009	283·85	46·17	+ 7·1	5	H	− 2·6
2010	283·87	46·19	+ 2·	1·5	H	− 7·7
2019	285·87	48·19	+ 3·6	3·	C	− 5·7
2020	285·90	48·22	+ 0·3	2·5	C	− 9·0
2025	286·67	48·93	− 3·0	3	P'	12·2
2034	292·82	55·14	+ 8·9	5	C	0·0
2035	292·85	55·17	2·8	4	C	− 11·7
2051	297·85	60·17	+ 2·6	5	C	− 6·0
2133	320·79	83·11	+10·3	7·5	C	+ 0·4
2147	322·78	85·10	+ 6·2	2·	P'	− 4·1
2230	341·70	104·02	+11·8	6	H	− 0·2
2257	346·72	109·04	+20·7	6	P'	0·0
2339	374 70	5·70	+51·7	6	P'	− 3·0
2380	381·69	12·75	+35·9	5	P'	+ 3·2
2410	388 67	19 73	+30·0	4	P'	+ 8·0
2428	389·66	20·72	+30·9	6	C	+ 9·9
2446	397·62	28·68	+24·2	7	H	+ 9·0
2524	425·55	56·61	+12·6	7	H	+ 3·8
2781	557·89	57·69	+14·0	7	P'	+ 5·3
2808	570·88	70·68	+ 9·0	4	C	+ 0·2
2809	570·91	70·71	+ 7·1	6	C	− 1·7
2831	578·89	78·69	+ 8·8	8	C	− 0·4
2832	578·92	78·72	+10·1	7	C	+ 0·8
2844	584·81	84·61	+ 5·6	6	H	4·6
2870	588·84	88·64	+ 3·9	5	P'	− 6·0
2877	588·87	88·67	+ 0·1	4	P'	− 10·8
2898	599·95	99·75	+19·6	5	C	+ 4·7
2907	600·84	100·04	+ 9·5	6	C	− 5·7
2908	600·90	100·70	+20·4	8	C	+ 5·0
2927	609·86	109.66	+16·0	8	P'	5·3
2928	609·90	109·70	+20·9	8	P'	− 0·3
2939	619·95	119·75	+38·4	8	H	+ 1·4
2942	620·88	120·68	+47·	2	C	+ 7·1
2948	623·77	123·57	+54·5	7	P'	+ 5·0
2949	623·81	123·61	+49·0	8	P'	− 0·5
2957	626·82	126·62	+64 8	7	P'	+ 2·0
2958	626·85	126·65	+60·3	7	P'	2·5
2963	634·78	3·32	+73·1	8	H	+ 6·1
2970	634·82	3·36	+72·5	7	H	+ 5·5
2977	637·66	6·20	+60·2	6	H	+ 7·7
2978	637·69	6·23	+55·8	7	H	+ 3·3
2986	641·87	10·41	+48·8	2	C	+ 10·8
2998	642·68	11·22	+27·0	7	P	8·6
2999	642·70	11·24	+30·0	8	P	− 5·5
3094	682·04	51·18	+ 1·3	5	H	7·7

Plate	Julian Date	Phase	Velocity	Weight	Observer	O − C
3099	2,418,684·60	53·14	+ 10·0	2	P	+ 1·0
3100	685·67	54·21	+ 10·5	3	P	+ 1·6
3101	685·71	54·25	+ 2·6	6	P	6·2
3143	697·79	66·33	+ 4·4	5	P	− 4·3
3159	703·63	72·17	+ 12·0	4	C	+ 3·2
3160	703·67	72·21	+ 5·8	3	C	3·0
3203	724·62	93·16	+ 16·4	8	C	+ 4·0
3319	742·57	111·11	+ 25·4	9	H	+ 2·3
3320	742·60	111·14	+ 17·7	7	H	− 5·4
3351	747·60	116·14	+ 27·6	7	P′	2·2
3352	747·64	116·18	+ 24·5	8	H	5·3
3356	754·63	123·17	+ 37·7	3	P′	6·7
3361	759·59	128·13	+ 65·3	7	C	3·7
3362	759·62	128·16	+ 75·8	6	C	+ 6·8
3369	763·55	0·83	+ 81·6	5	H	+ 6·0
3370	764·52	1·80	+ 66·7	8	P	6·0
3373	765·52	2·80	+ 67·0	7	H	− 2·0
3374	765·55	2·83	+ 64·9	9	H	4·1
3390	775·57	12·85	+ 29·1	7	P′	3·0
3401	784·55	21·83	+ 15·3	5	H	4·7
3404	787·56	24·84	+ 21·8	1	C	+ 3·0
3653	929·02	35·94	+ 17·9	3	C	+ 5·6
3670	931·87	37·89	+ 17·2	2	P′	+ 5·4
3671	931·91	37·93	+ 7·6	4	P′	4·2
3688	936·01	42·93	+ 17·2	4	C	+ 6·9
3703	943·88	49·90	+ 16·7	2	C	+ 7·5
3704	943·91	49·93	+ 6·4	3	C	2·8
3822	9,011·87	117·89	+ 32·4	4	H	0·6
3823	011·90	117·92	+ 34·0	4	H	+ 1·0
3828	012·89	118·91	+ 35·4	5	P′	+ 0·4
3837	014·71	120·73	+ 43·3	6	H	+ 3·3
3847	015·82	121·84	+ 48·0	8	P′	+ 5·0
3865	018·89	124·91	+ 54·2	4	H	+ 0·2
3878	022 69	128·71	+ 77·5	7	H	+ 5·8
3879	022·73	128·75	+ 82·0	5	H	+ 10·3
3890	027·75	2·51	+ 72·7	6	P′	+ 1·4
3908	036·70	11·52	+ 33·6	5	H	1·4
3909	036·79	11·55	+ 31·6	6	H	3·4

For convenience of reference the early measures of Frost and Adams are appended :

YERKES MEASURES OF ν ORIONIS

Date	Julian Date	Phase	Velocity	Residual from Ottawa Curve
1903 Jan. 22	2,416,137·85	0·33	+ 81	+ 4·8
Oct. 31	419·94	19·90	+ 21	− 0·8
Nov. 14	433·90	33·86	+ 12	− 0·8

The first plate was stated to have such broad and fuzzy lines owing to the dispersion of three prisms used that the result was

considered only a rough approximation. In a personal communication to the writer Professor Frost gives the velocities from the different lines used. These agree among themselves very closely and he suggests that the plate should be given considerable weight and no doubt its result is close to the actual velocity. The period that suits all observations best is that given, viz.: 131·26 days, though possibly the first decimal place is as close as this can be relied on.

With this period the plates were grouped according to phase into fourteen normal places. The weights given to each group was approximately the sum of the individual plates comprising the group.

NORMAL PLACES

	Mean Phase	Mean Velocity	Weight	O − C	Equation-Ephemeris
1	2·77	+ 69·23	5·	− ·28	·05
2	5·93	55·25	3·	+ ·50	+ ·10
3	11·75	31·69	4·5	− 3·22	+ ·12
4	18·09	26·21	5·	+ 3·47	+ ·05
5	41·55	11·18	7·	+ ·56	·04
6	56·46	7·99	4·5	·05	·04
7	71·13	7·59	4·5	− 1·07	− ·06
8	84·52	8·38	5·	1·83	·05
9	93·05	15·46	4·5	+ ·68	·03
10	109·27	21·98	5·5	+ ·82	·03
11	116·05	30·66	4·5	·63	+ ·01
12	121·63	44·27	6·	+ 1·73	+ ·18
13	126·82	61·19	5·	2·06	+ ·40
14	130·10	+ 78·79	2·5	+ 3·19	+ ·17

Preliminary elements were obtained by the graphical method of Dr. King* as follows:

$$P = 131{\cdot}26 \text{ days}$$
$$e = {\cdot}575$$
$$\omega = 0{\cdot}^{\circ}$$
$$K = 33 \text{ km.}$$
$$\gamma = + 21{\cdot}53 \text{ km.}$$
$$T = \text{J. D. } 2{,}417{,}974{\cdot}69.$$

With these elements it was decided to make a least squares solution. Using the differential form† of Lehmann-Filhés.

* *A. J.*, Vol. XXVII, No. 2, 1908, p. 27.

† *A. N.*, 3242.

fourteen observation equations were formed connecting the residuals with the elements γ, K', e, ω and T. The period was considered determined as closely as could be.

The following corrections resulted:

$$\delta\gamma = + \cdot57 \text{ km.}$$
$$\delta K' = + 1\cdot09 \text{ ''}$$
$$\delta e = + \cdot024$$
$$\delta\omega = + 1^\circ\cdot58$$
$$\delta T = + \cdot47 \text{ d.}$$

giving as the corrected elements, with their probable errors,

$$P = 131\cdot26 \text{ days}$$
$$e = \cdot599 \pm \cdot014$$
$$\omega = 1^\circ\cdot58 \pm 2^\circ\cdot12$$
$$\gamma = + 22\cdot10 \text{ km.} \pm \cdot47 \text{ km.}$$
$$K' = 34\cdot09 \text{ km.} \pm \cdot75 \text{ km.}$$
$$T = \text{J. D. } 2{,}417{,}975\cdot16 \pm \cdot38 \text{ days}$$
$$A = 54\cdot50 \text{ km.}$$
$$B = 13\cdot68 \text{ ''}$$
$$a \sin i = 49{,}270{,}000 \text{ km.}$$

The sum of the squares for the normal places lowered from 298·5 to 205·9, about 31 per cent. The residuals given in the table of normal places are those from the final elements. The agreement between equation and ephemeris residuals was satisfactory, so that no further solution was necessary.

The probable error of a single observation obtained from columns 5 and 7 of the Measures is $\pm$ 3·47 km. per second. For this type of spectrum one would expect that this value should be somewhat lower, but remeasurement of many of the plates giving large residuals failed to make any sensible difference in the results. In a few cases, as may be noted in the measures, plates made consecutively on the same night differ from each other by 10 to 12 km. per sec. so that the above value was not unexpected.

Quite recently Mr. Jordan*, of the Allegheny Observatory, in discussing the orbit of π Andromedæ, calls attention to the

* *Publications of the Allegheny Observatory*, Vol. II., No. 8.

large gap between the short and long periods for the helium stars. The star under discussion here furnishes another illustration of the marked increase of eccentricity with period, the value of e being ·60 for an orbital period of 131· days.

The curve shown represents the corrected values of the elements.

The interest shown and the encouragement given by the Director in this work is hereby gratefully acknowledged.

Dominion Observatory,
Ottawa, Canada,
January, 1911.

CHANGES IN FOCUS PRODUCED BY PLANE GRATINGS

By Ralph E. DeLury

TWO plane gratings of speculum metal have been tested in the Littrow Spectrograph of the Observatory. One of these, grating (*a*), having a 10 cm. × 12 cm. ruled surface and about 500 rulings to 1 mm., exhibited peculiarities in its focal properties, produced poor spectra and lacked brilliancy to a decided degree; the definition of spectral lines produced by it was greatly improved by masking 2·5 cm. or more off each end of the rulings and 6 or 7 cm. off one side of the grating where it was seen by direct reflection to be of different character from the rest of the grating. It was finally returned to the makers and one of their latest products, grating (*b*), having a 10 cm. × 13 cm. ruled surface and about 700 rulings to 1 mm., was obtained. This grating showed nearly normal properties and proved to be much more brilliant than the first grating; and when 5 or 6 cm. off one end of the rulings and about the same amount off one side of the grating were masked, the definition of the spectral lines became excellent. The peculiar changes in focus found in the case of the first grating do not in themselves lessen its value, but they are probably intimately connected with its defects and may possibly serve to indicate their cause.

The optical part of the spectrograph* consists of a slit, a 15 cm. (6 in.) lens placed at its focal length (nearly 7 m., or 23 ft.) from the slit, and a grating mounted about 18 cm. back of the lens in its mean position, with its rulings parallel to the slit. Light is directed through the slit so as to nearly fill the lens, which, when placed its focal length from the slit, for the wavelengths under consideration, throws a parallel beam of light on

* Described in detail in The Report of the Chief Astronomer for the year ending March 31, 1909, p. 251.

the grating. The grating diffracts the light back through the lens which focusses the spectrum at the slit. By tilting the grating forward slightly, the spectrum is focussed a little below the slit where it may be conveniently photographed or examined with the aid of an eye-piece. To avoid light reflected from the surfaces of the lens, it is necessary to mask a strip across the middle of the lens, or better, to tilt the lens slightly, as suggested by Mr. R. M. Stewart. The former method was employed in the measurements recorded below, but the latter arrangement has since been adopted: in either case the axis of the lens passed through a point midway, or a little below midway, between the slit and the place where the spectrum was focussed. However, since the distance between the slit and the point where the spectrum was focussed is only 10 cm., it may be assumed for the purposes of this note that the slit and spectrum are coincident on the principal axis of the lens.

If the grating be placed normal to the beam of light it will act as a plane mirror and reflect back the light through the lens which will focus the light of different wave-lengths at various distances from the slit. By sliding the lens back and forth the different colored images of the slit may be focussed in turn at the slit, employing suitable filters to cut off the light of other colors. This has been done for the colors admitted through the red, green and blue filters of an Ives' tri-color outfit, and a "Filtergelb" screen; and the distances of the lens from the slit, or the foci, for these colors have been recorded. If the grating be turned about a vertical axis to either the left or right, the orders will appear in succession from violet to red. The distances of the lens from the slit necessary to focus the light of the different orders at the slit have been determined for the various angles of turning of the grating. All these observations are plotted in Figure 1 for both gratings, (*a*) and (*b*). The measurements were nearly all made visually, and individual observations may be in error from 2 to 6 mm. The measurements with (*a*) were made at a temperature of 20°-21° C., while those with grating (*b*) were made at about 18° C. A few observations indicate that a

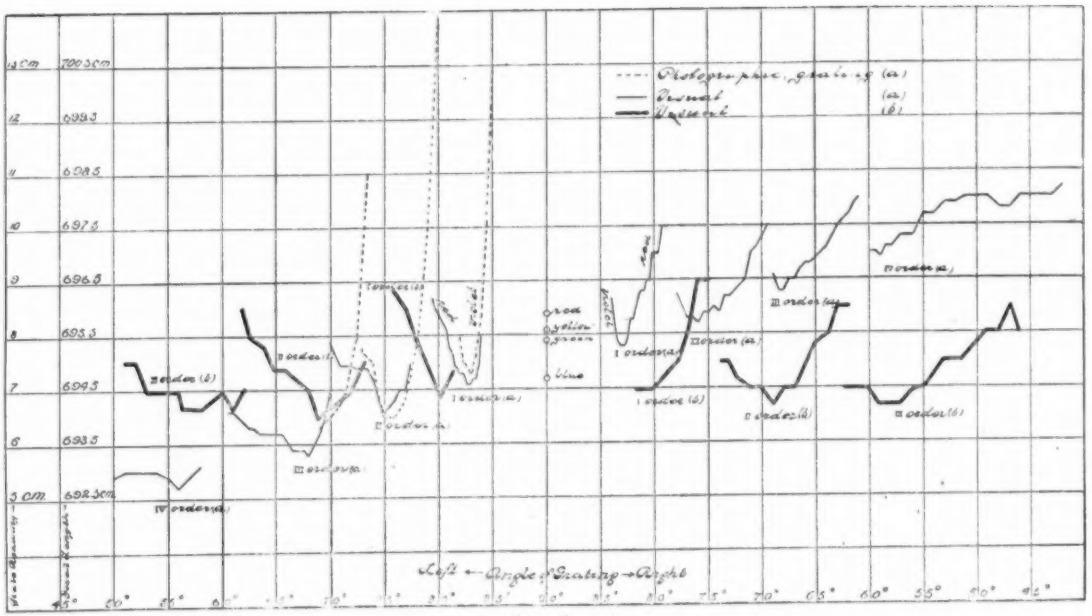


FIG. 1.

ILLUSTRATING CHANGE OF FOCUS PRODUCED BY A PLANE GRATING

decrease in temperature of 1° C. increases the focus of the lens nearly 1 mm.

A reference to Figure 1 shows that the focus for any color or wave-length varies progressively from order to order of grating (*a*), while it remains nearly constant in the different orders of (*b*). This will be more apparent if it is remembered that,

$$n.\ \lambda\ =\ 2.\ \frac{1}{s}.\ \sin\theta,$$

for a Littrow Spectroscope, n being the order, λ the wave-length in 10^{-10} metres, s the number of rulings to the mm. — 500 and 700 for gratings (*a*) and (*b*) respectively, — and θ the angle of inclin-

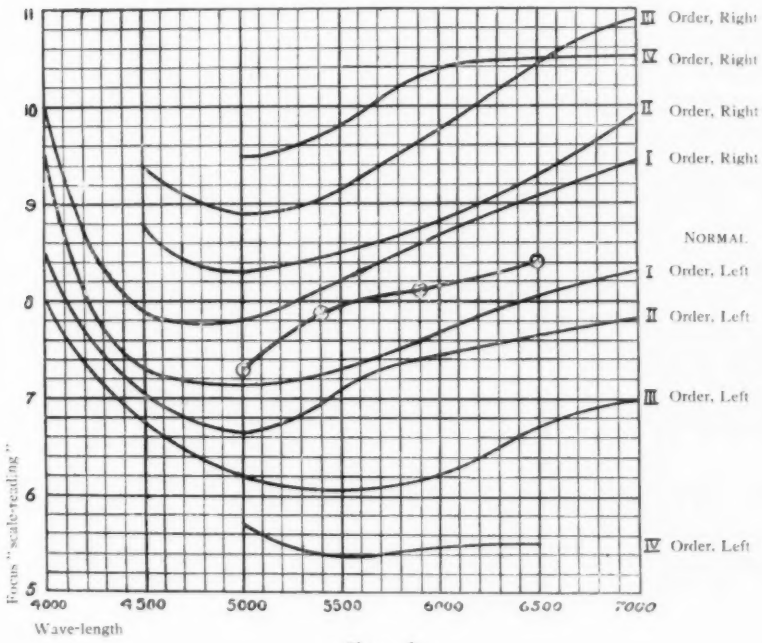


FIG. 2

ILLUSTRATING CHANGE OF FOCUS PRODUCED BY A PLANE GRATING

ation of the grating from the normal, *i. e.*, 90° minus the "angle of grating" given in the Figure.

The relation between change of focus and wave-length for the different orders of grating (*a*) is more clearly shown in Figure 2, where the wave-lengths and focus "scale-readings" are the abscissæ and ordinates respectively. The "normal" focal curve is not known accurately since the average wave-length transmitted by the filters employed is not known very closely and the measurements of focus could not be made with great accuracy on account of the diffraction fringes; however, it is safe to assume that it lies nearly as represented in Figure 2, about midway between the focal curves of the two first orders.

A close inspection of these curves shows that, within the limits of the errors of measurement, the change in focus is proportional to the wave-length and to the order, being negative when the grating is turned to the left and positive and of equal magnitude to these changes when it is turned to the right. A fairly accurate value of the decrease or increase in focus for any wave-length in any order is found, by taking half the difference between the foci for the wave-length in the right and left focal curves of that order. Such differences are given in the following Table:

λ	I, R. — I, L.	II, R. — II, L.	III, R. — III, L.	IV, R. — IV, L.
4500	0·6 cm.	1·7	2·7	——
5000	0·7	1·7	2·7	3·8
5500	0·9	1·4	3·1	4·4
6000	1·0	1·4	3·5	4·9
6500	1·1	1·7	3·7	5·0
7000	1·2	2·1	3·9	——

From this Table a mean value of the change in focus from the normal, of $\pm\ n\ 0{\cdot}5$ cm. for say λ 5750 may be derived, and for any wave-length, λ, the change in focus,

$$d = \pm\ n.\ 0{\cdot}5\ \frac{\lambda}{5750}.$$

Hence, substituting the value for $n\ \lambda$ mentioned above, it follows that,

$$d = \pm \frac{10^7}{500^2} \cdot \frac{\sin \theta}{5750} \text{ cm.}$$

Thus it appears that the change in the focus is proportional to the sine of the angle of inclination of the grating, being negative when the grating is turned to one side and positive when it is turned to the other. This fact is of great importance in deciding on a theory to account for these changes.

After I had made the focal measurements for this grating, two theories to account for the changes in focus suggested themselves ; one, to Mr. Plaskett, that the changes in focus were due to curvature of the ruled lines ; the other, to me, that it was due to curvature of the grooves caused by the ruling point pressing over the ridge between the last furrow made and the one being made, thus producing a concave and a convex side to each furrow. If the latter theory were correct, the second grating should show a somewhat similar behaviour to the first ; it behaves quite normally, however, and the proportionality of the changes to the sine of the angle of inclination of the grating taken along with this fact, make it seem quite probable that the former theory is the correct one. If, then, it be assumed that curvature of the ruled lines causes the changes in focus, it is possible to calculate the amount of this curvature from the changes in focus, as follows :—

Let the normal focus of the lens for any wave-length be f cm. (*i. e.* the lens must be f cm. from the slit in order to focus the light of the particular wave-length at the slit). Let the focus be changed to $f + d$ on account of the curvature of the ruled lines ; the light emerging from the lens to the grating will be convergent or divergent as d is positive or negative. Now, in order that the spectrum may be focussed at the slit, the grating must return the light along the same path, *i. e.*, it must act as a convex or a concave mirror depending on whether d is positive or negative respectively. Suppose the grating does this, then its radius of curvature r, is given by the formula,

$$\frac{1}{f} = \frac{1}{f+d} - \frac{1}{r}, \text{ or, } -\frac{1}{r} = \frac{d}{f^2}$$

r being negative (*i. e.*, as for a convex mirror) when d is positive: and positive (*i. e.*, as for a concave mirror) when d is negative. It is desired to know the curvature of the lines measured in the plane of the grating, *i. e.*, corresponding to the value of d when $\theta = 90°$, a value, of course, impossible in practice. For this value of θ,

$$d = \pm \frac{10^7}{500} \cdot \frac{1}{5750} \text{ cm., or, } \pm 3{\cdot}5 \text{ cm.,}$$

and the normal value of f for λ 5750, is about 659·5 cm. Consequently, r is found to be about 140,000 cm. This would mean, in a ruling 10 cm. long, a departure at the ends from the position of the centre of the ruling, of about 0·00008 cm., or about half the distance between two successive lines of the grating. Such a condition would account for all the defects of the grating in question, and possibly irregularity in the form of the grooves would help to account for its exceptional dimness.

It may here be mentioned that such measurement as recorded above may sometimes serve to point out—to those who have undertaken the extremely difficult task of ruling gratings—slight errors in the ruling mechanism which may be removed.

Dominion Observatory,
Ottawa, Canada,
December 1910.

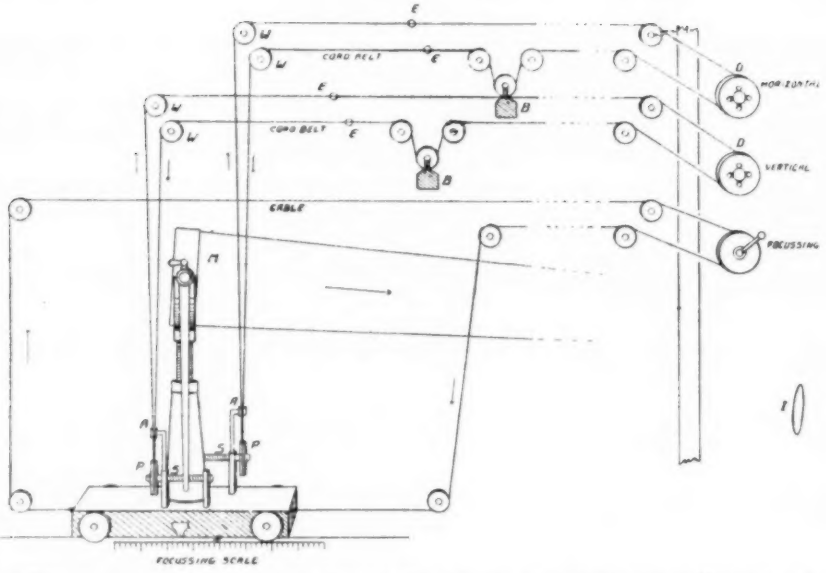
A DEVICE FOR GUIDING THE IMAGE PRODUCED BY A CŒLOSTAT TELESCOPE

By Ralph E. DeLury

THE image produced by a cœlostat telescope is subject to regular and irregular shifting of position caused by changes in atmospheric refraction, in the speed of driving of the cœlostat clock-work and in the position of the cœlostat mirror if it rotates about an axis not in its plane. In some investigations it is important to keep the image in a definite position for a considerable time, and it is, therefore, necessary to have a convenient means of quickly correcting any changes from this position. For example, in taking a photograph of a sun-spot spectrum it is essential to keep the image of the spot on the slit of the spectrograph and not allow the image to drift, in which case light would be admitted from another part of the sun. A simple device for checking any drifting of the image or for placing it in any required position, is illustrated in the accompanying figure.

The cœlostat directs a beam of light to *M*, the concave mirror, which produces the image and to which are clamped two arms connected with screws *S*, *S*, working in bearings on the cast-iron support of the mirror. By turning these screws the two arms may be moved back and forth, giving *M* rotations about a horizontal and a vertical axis, which move the image, *I*, in vertical and horizontal directions respectively. The following device provides the means for producing these movements from a position near the image:

To the screws, *S*, *S*, are fastened the pulleys *P*, *P*, in which run stout woven cord belts. These belts are carried over screw-pulleys, *W*, *W*, and through eyes *E*, *E*, and around the turning drums *D*, *D*, which are placed on the wall close to where the image, *I*, is to be observed. By turning the handle of one drum ("*Vertical*") the image may be raised or lowered; while turn-



A Device for Guiding the Image Produced by a Cœlostat Telescope

ing the other drum ("*Horizontal*") moves the image back and forth in a horizontal direction.

Climatic changes alter the lengths of the woven cords so that they may slip on the drums: the cord belts should then be retightened. By passing them several times around the drums and by waxing both the drums and cords with beeswax, small changes do not cause much trouble. All changes, however, may be compensated if springs or adjusting-screws be put in the belts, or if pulleyed weights *B*, *B*, (as suggested by Dr. King) be hung on the belts to keep them at constant tension. Such an arrangement has been used for the past year and a half with the 80 foot cœlostat reflecting telescope at the Dominion Observatory, and it has been found very useful and satisfactory in the solar work. The concave mirror mounting had been already provided with the arms and screws *S*, *S*, working in them so that it was an easy matter to attach the system of pulleys, drums and cord belts.

In some observatories electric motors are used for guiding, but the method described above is probably just as satisfactory and is much less expensive.

A mechanism similar to the guiding device may be used for "focussing" the image at any desired place or for correcting the changes in focus produced by the changing temperature of the mirrors. Such an arrangement is illustrated in the figure ("*Focussing*"). It is desirable in this case to use a wire cable and to turn the drum by means of a crank. Arms A, A, should also be used to keep the strings playing vertically in the pulleys so that they will not slip out of them.

I wish to express here my thanks to the Director, Dr. W. F. King, for his kindness in providing for this additional convenience in the Solar Laboratory.

DOMINION OBSERVATORY
OTTAWA, CANADA
December, 1910

PRECISE MEASURING WITH INVAR WIRES; AND THE MEASUREMENT OF KOOTENAY BASE.

By P. A. Carson.

THE first essential in measuring linear magnitudes is of course a unit of length. And what a babel of units there is, every age and every people contributing their share to the confusion. Fortunately, however, by the concurrent action of the principal governments of the world, we now have a recognized standard unit, viz.: the international metre, which is copied after the French metre. The international metre is defined as the distance between two lines at 0° C on a platinum-iridium bar deposited at the International Bureau of Weights and Measures, Sèvres, France. Prototypes of this standard metre have been formed and distributed amongst the different countries. These are called national prototype standards.

It is obvious, however, that these standards must be guarded with the greatest care, and cannot be used in performing actual measurements. Consequently, the next essential is a measuring unit. This measuring unit generally takes the form of a bar or tape; and the errors in the value of a base measured with such arise from two principal sources, viz.: comparisons and measurements. Errors in the comparisons which determine the length of the measuring bar or tape are accumulative, and it is of the utmost importance that the standardizing of the measuring unit should be performed with the greatest precision. Also that the bar or tape should either have a permanent length or change only according to known laws.

The greatest source of error due to measurements has always been the uncertainty in the temperature, and hence of the length of the measuring unit during the field operations; first, because during changing temperatures the recording thermometers rarely measure the true temperature of the bar or tape, and secondly,

because the volumetric change in metals generally lags behind the temperature change. The earlier measurements of base-lines in connection with geodetic triangulations were performed with wooden contact rods. These were superseded by iron rods, glass tubes, steel bars and steel chains, but in all the errors due to temperature were beyond control. To evade the temperature difficulty many ingenious compensating apparatus were devised, such as the Borda and the Colby apparatus, which were based on the different rates of expansion of two metals. These instruments while theoretically perfect were soon found faulty in practice and were abandoned. The U. S. Coast and Geodetic Survey Iced-bar Apparatus is one of the most precise instruments for base measurement, the temperature difficulty being avoided by packing a steel bar in ice. But this apparatus is very cumbersome and takes a small army of men to handle it. It is, therefore, too expensive for general use. The modern steel tape affords a very exact, rapid and economical method of measuring even primary bases. This method has reached a high degree of perfection in the United States, by taking great precautions for temperature changes and making the measurements at night.

Several years ago M. Ch. Guillaume, Assistant Director of the International Bureau of Weights and Measures, in making researches with alloys of nickel and steel, discovered that an alloy of these two metals containing about thirty-six per cent. of nickel possesses a very small co-efficient of expansion and its use was immediately suggested for base measurement. To this alloy has been given the name "invar," a word derived from the same root as the word "invariable" and having a similar meaning.

By the use of invar in the form of wires, and an ingenious apparatus devised by M. Guillaume (hereinafter described), we now have at our command a base measuring instrument capable of the same accuracy as the most refined bar apparatus, and at the same time much more convenient and economical. It has also many advantages over steel tapes in that the invar wires may be standardized at any Bureau of Standards instead of in the field, greater precision can be attained, the work may be done

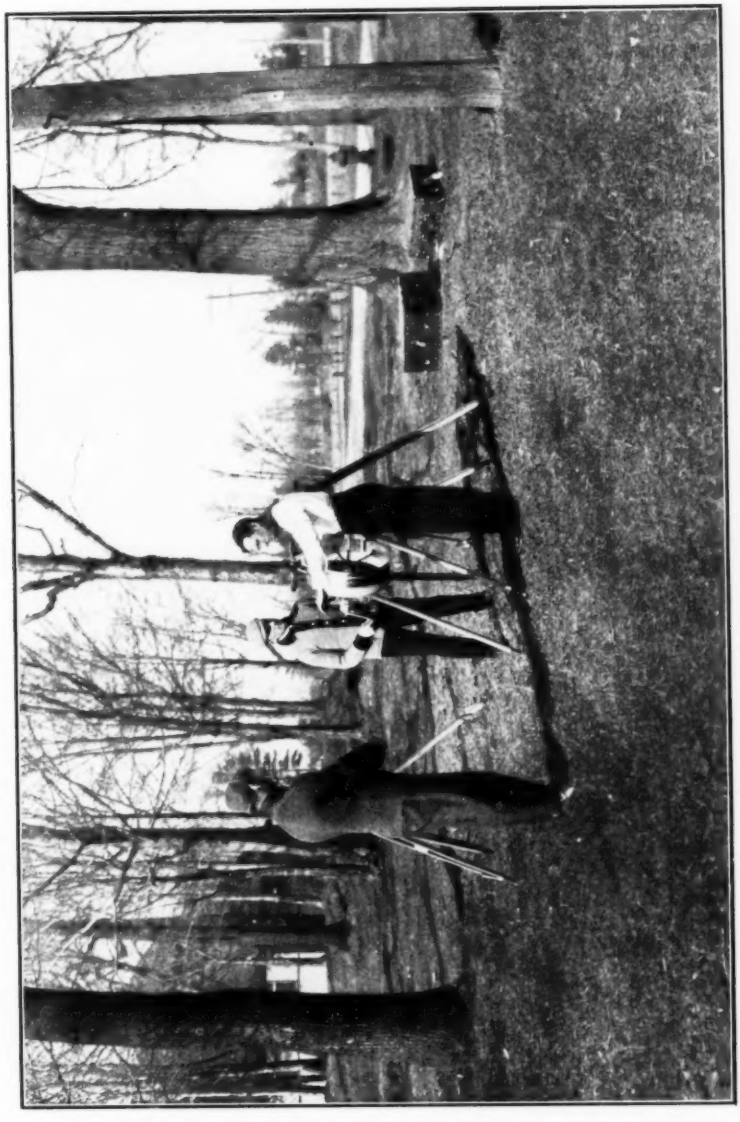
in day time, and errors due to uncertain temperatures are almost entirely eliminated.

For the complete manual of the theory of invar and the description of the base-line apparatus, reference should be made to "La Mesure Rapide des Bases Géodésiques" (4th edition) by J. Rene Beniot and Ch-Ed. Guillaume, of the International Bureau of Weights and Measures. It has been considered advisable, however, to give in connection with this report a brief discussion on the theory and peculiarities of that strange alloy termed "invar," together with a description of the salient features of the apparatus, and its application to the rapid and precise measurement of geodetic base lines.

Properties and Manufacture of Invar: Alloys of nickel and steel exhibit many peculiar and interesting properties especially in their action under different thermal conditions. This anomaly of dilatation was observed by M. Guillaume. As the percentage of nickel is increased above 25 per cent. the dilatation decreases very rapidly and reaches a minimum with 36 per cent. nickel; then it rises again rapidly, and as the percentage of nickel is increased approaches slowly to the dilatation of pure nickel.

Invar is more like nickel than steel in appearance. It is less easily oxidised than steel, yet requires some care to keep it free from rust, especially in moist climates. This may be done by rubbing with a rag covered with vaseline, as the small spots of rust which sometimes appear on the surface do not adhere very closely, and may be easily removed in this manner. The alloy is very ductile, yet at the same time quite tenacious. It laminates and is made into wires very easily, but quickly wears out files and other hard tools. In the malleable state it will submit to great alterations in shape without rupture, while on the contrary, when it has been laminated or drawn into wires, it reaches a state of elasticity suitable for ordinary springs. The modulus of elasticity of invar in the form of cold-drawn and hammered wires is about 16,000 Kg.: mm.^{2}, its tensile strength being about one-half of that of steel. One of the peculiar properties of invar is that its modulus of elasticity increases with an

PLATE I.



UNROLLING THE INVAR WIRES

increase of temperature which is contrary to all other known metals.

Invar intended for geodetic purposes is made by certain steel manufactories in France, the usual additions of manganese, silicate, and carbon being reduced to a minimum. Specimens of each casting are then examined, and only those which possess the requisite small coefficient of expansion are accepted. These are then made into wires, being forged at very high temperatures, and cold-drawn and hammered at low temperatures. They are reduced to an average diameter of two millimetres by means of steel wire-machines, and then made to the definite diameter of 1·65 mm. through ruby holes, which give a smooth surface and a uniform diameter.

Étuvage.—Invar wires so manufactured are, however, by no means ready for use, but must be carefully studied and examined in the laboratory. It has been observed that invar in the course of time shows a gradual permanent lengthening extending over a number of years, which lengthening approaches slowly towards a limit which seems definite. The value of this limit depends on the temperature and the progress is more rapid as the temperature is higher. This permanent lengthening is considerably minimized by a peculiar treatment of the alloy, termed 'étuvage.' The wires are rolled on a spool-like cylindrical boiler of 50 cm. diameter, forming a kind of drum. The boiler is filled with water, which is kept at boiling point (100° C) for several days. This temperature is then lowered gradually so as to reach 40° C or even 25° C in about three months, the alterations in temperature becoming slower as the temperature decreases. By submitting the wires to this process of 'étuvage,' they undergo the series of changes which would have taken a great number of years to accomplish at ordinary temperatures, and which changes will not now take place again. Even after the étuvage process is completed there is still for some time a gradual though small lengthening. This change is rather rapid at first, then becomes less and less and it is wise to keep the wires for some months before attempting to determine their absolute length.

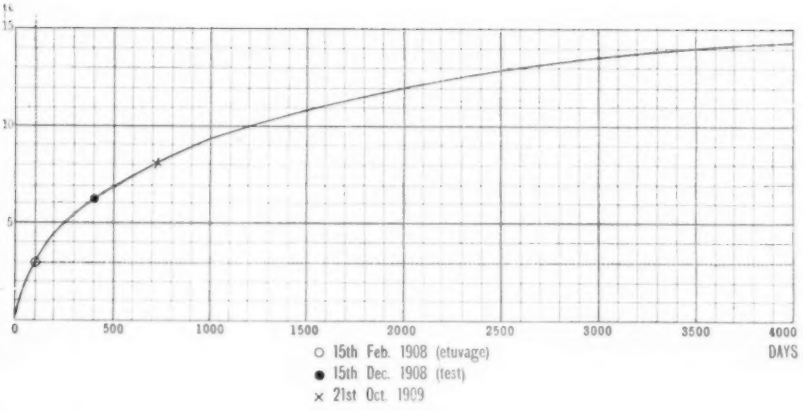


FIG. 1

The curve in Fig. 1 shows the gradual permanent lengthening, which takes place in the course of time, in an invar bar, one metre long, which has been treated by the étuvage operation, the temperature being reduced to 40° C, then kept at that of the laboratory (6° C to 22° C). The abscissæ represent the number of days after étuvage and the ordinates the lengthening in microns (μ) per metre (a micron being the one-millionth part of a metre).

When the temperature of the étuvage is lowered to 25° C instead of 40° C, the origin of the curve is decreased by one hundred days and three microns, as shown by the dotted lines in the figure.

Record is kept of the dates of étuvage, and of the standardizing tests, and from the curve we can determine what alteration in length has taken place in the interim. When the wires are used for field measurements we must note the date and reckon the number of days since étuvage or test. By plotting off the correct distance along the abscissa the curve will show in microns per metre the gradual lengthening of the wire, and

therefore we have the quantity which must be added to the value of the wire obtained in the standardization.

The corrections given by the curve ought to be considered at least for the first two years, only as an approximation to the millionth part.

Periodic and Daily Temperature Dilatation.—Although the expansion of invar due to temperature is very small, it is by no means negligible. When the temperature of invar is altered a change in length takes place. This change is of two kinds, termed daily and periodic, the first of which is by far the greater, and occurs simultaneously with the change in temperature. The periodic change, which is very small, follows the other slowly, and corresponds to the lag of other metals. When the new temperature is greater than the first, the periodic variation is a contraction and conversely. In order to apply this second correction for the thermal variation we proceed as follows:—If we have an invar wire to be used in measuring a base line, we consider the mean temperature for the weeks which precede the measurements to be a temperature which is slowly reached, and the periodic variation will tend to approach the change corresponding to this mean temperature. The following formula of periodic dilatation has been established by observations with the comparator:—

$$\Delta l = -0{\cdot}00325 \times 10^{-6} \times l t.$$

l being the temperature reckoned from zero.

The numerical coefficient of this formula is very small, consequently an error of five or six degrees does not affect the length of the wire one in a million.

To determine the periodic temperature dilatation of invar wires Nos. 272 and 273, which were used in the measurement of Kootenay base, the maximum and minimum temperatures of the wires were recorded each day for the fortnight preceding their use. The mean temperature for this period was 7°·4 C, and is practically the same as the mean temperature of the wires during the measurements.

We, therefore, have from the above formula

$$\Delta l = - 0{\cdot}00325 \times 10^{-6} \times (7{\cdot}4^2 - 15^2)\ 24^m = + 0^{mm}{\cdot}0133.$$

This quantity may be added once for all to the value of the wires for the measurements under consideration.

Daily Temperature Dilatation.—The ordinary changes in the temperature recorded during the actual measurements determine the daily thermal corrections, which are applied from the regular coefficient of expansion. For wires Nos. 272 and 273 this formula for the range of ordinary temperatures is

$$\Delta l = (- 0{\cdot}121 + 0{\cdot}00015\ t)\ 10^{-6}\ t\ l$$

and when expanded in a table for each degree from 0° C to say 30° C, gives the correction to be applied to the length of the wire for each recorded temperature.

The above formula is not the formula of absolute expansion but is the dilatation of the wires when under a tension of ten kgs. The elastic deformations decrease as the temperature increases, therefore this expansion of invar is slightly less than the free or absolute dilatation. It should be noted that this formula is negative, as the lengths of the wires decrease as the temperature rises.

The thermal expansion of steel is, therefore, about one hundred times as great as that of invar wires Nos. 272 and 273.

Mechanical Treatment of Wires to assure permanence in length.—As geodetic wires must necessarily be rolled for transportation, it is important to note what effect the continual rolling and unrolling might have on the length of the wires. Numerous observations have shown that an invar wire, cold-drawn and hammered, may be rolled in a diameter of fifty c.m. without suffering any alteration in length. Each wire before it leaves the Bureau is submitted to numerous rollings and unrollings for an extended period of time, and observations are made upon its length before and after until permanence is assured. Great care must be exercised that no portion of a wire shall be rolled in a diameter

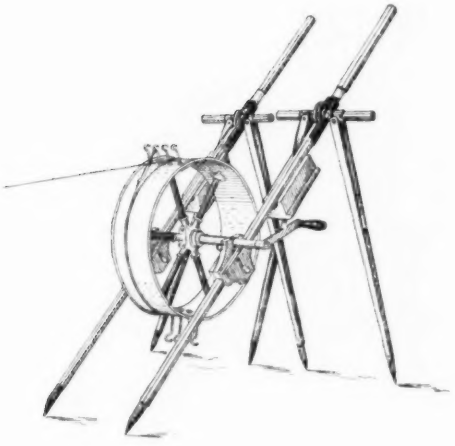


FIG. 2.

of less than fifty cm., lest a degree of instability may be caused which will produce permanent changes of which the wire can rid itself only very slowly.

The wires for transportation are rolled on an aluminum drum of fifty cm. diameter as shown in figure 2. The six spokes of the drum are of steel; the outer rim is of aluminum, is about sixteen cm. wide, and will hold four twenty-four metre wires. The ends of the wires are fixed to two pairs of hooks fastened to the rim of the drum so that the end scales are tangential to the circumference. For winding and unwinding, the drum is fixed to a steel axle with a handle, and the whole is attached to the two tension tripods placed side by side. When not in use the drum and wires are kept in a specially designed trunk. The wires should be rolled rather loosely on the drum so as to avoid dangerous tensions due to the difference in expansion of the drum and wires. When the wires were reeled and put away after the measurement of the Kootenay base, the tem-

perature of the air was about 3° C. Consequently the drum was heated to about 20° to avoid subsequent excessive expansion.

The wires are also treated by another mechanical process, being a system of rythmic beating on the floor, which operation tends to produce a condition of stable equilibrium in the particles of the alloy and prevents unknown alterations in length from accidental disturbances such as might occur during long railway journeys and other rough usage.

Wire which are used under constant tension of say ten kg. are also tested by excessive tensions for periods of 24 hours, and any danger of accidental lengthening from sudden shocks or prolonged forces thereby removed.

Standardizing Tests.— When the wires have been treated by the operations described above, and mounted at their extremities by graduated scales they are then ready for comparison to determine their absolute lengths. The graduated invar scales are of a special design which is very ingenious.

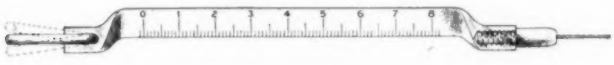


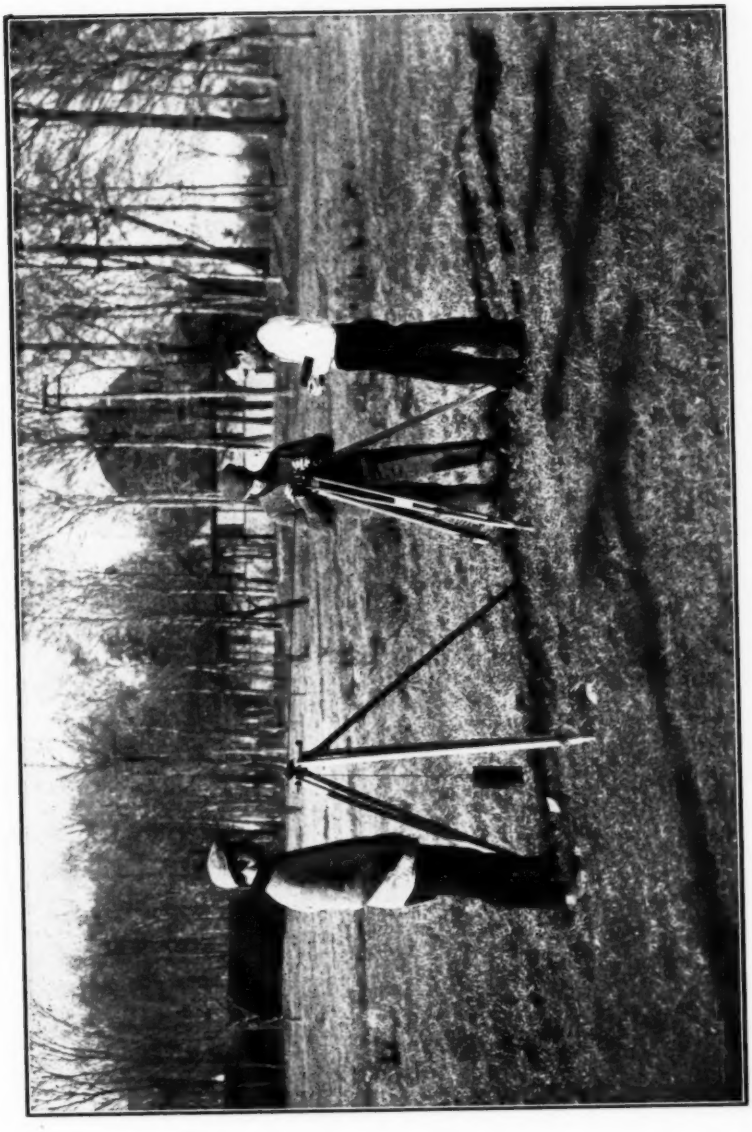
FIG. 3.

Figure 3 shows one of these scales, the graduated edge being hollowed so as to be in a direct line with the neutral axis of the wire. This form does away with errors in reading due to the terminal tangent to the curved wire not coinciding with the straight line joining the two extremities.

The standardization of the wires is made at the International Bureau, by exhaustive comparisons with the underground mural base, the wires being under conditions exactly similar to those under which they are used in field work.

The following certificate accompanied the wires received from the International Bureau of Weights and Measures by the Surveyor General of Dominion Lands.

PLATE II.



TAKING READINGS ON THE INVAR BASE LINE INSTRUMENT

INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES,

PAVILLION DE BRETEUIL, SEVRES (S. AND O.)

DECEMBER 2, 1910.

CERTIFICATE

OF INVAR WIRES, NOS. 272 AND 273.

Made by M. J. Carpentier, Paris. Belonging to the Surveyor-General, Canada.

Description

The wires, which are about 1·7 mm. in diameter, are terminated at each of their ends by invar scales, joined to the wires by a bolted piece to which they are screwed and rivetted.

Each of the scales is divided into mm. for a length of 82 mm., the centimetres being numbered from 0 to 8, the numbering being in the same direction at each end. The edge of the graduated scale is in a direct line with the neutral axis of the wire. One of the scales bears on its back this inscription: "J. Carpentier, Paris," and on the graduated side the numbers 272 and 273 respectively.

Tests

The wires were first submitted to a series of operations in order to assure the permanence of their lengths. Then they were compared to the mural base at the Bureau under the tension of 10 kg.

The series of comparisons were made from November 5, 1908, to January 4, 1909.

The wires were returned to the Bureau in September, 1910. They were immediately unrolled, and submitted to a new series of ten comparisons from September 19 to November 19, 1910. After which they were again rolled on their drum.

The comparisons were reduced to the mean temperature of 15° C. by means of the formula of dilatation

$$l_t = l_0 \, (1 - 0{\cdot}000{,}000{,}121\, t + 0{\cdot}000{,}000{,}000{,}15\, t^2)$$

determined from samples of these wires submitted to the same tension of 10 kg.

The following values were found for corresponding divisions on the scales:

VALUES OF THE WIRES AT 15° C. UNDER A TENSION OF 10 KG.

DATE	WIRE 272	WIRE 273
January, 1909	24 m. + 1·10 mm.	24 m. + 0·87 mm.
December, 1910	24 m. + 1.10 mm.	24 m. + 0·94 mm.

The determination of the dilatation of the wires was made by Mr. Ch. Ed. Guillaume, co-director of the International Bureau of Weights and Measures; the comparisons were made by Mr. Ch. Ed. Guillaume and Mr. L. Maudet, assistant at the Bureau.

(Signed) *J. Rene Benoit*,
Director of the Bureau.

The values of the wires for the measurements of Kootenay base was determined thus. The measurements were commenced on October 21, 1909. The two standardizations were made in December, 1908 and December 1910. The curve in figure 1, shows for October 21, 1909, an increase of 0·04$^{mm.}$ over the length in December, 1908. For wire 273, the second standardization in December, 1910, agreed almost perfectly with the increment corresponding to this date on the curve. Consequently, adding 0·04$^{mm.}$ to its value in December, 1908, as given by the certificate, we have, wire 273 = 24000·91$^{mm.}$ on October 21, 1909.

Wire 272, as will be observed in the certificate, did not lengthen according to the accepted law of the curve in figure 1. Indeed this wire showed in the second tests a length precisely the same as in the earlier ones. M. Guillaume thinks that the small permanent lengthening due to time was merely counteracted by a slight shortening induced by vibratory molecular motion during the long journey from France to British Columbia and return. It must be emphasized here, however, that we are discussing a very minute quantity, for in the measurements of Kootenay base, the values obtained by wires 272 and 273 differed only by 5·6 $^{mm.}$ in 8·5 kilometres.

To the value of each wire, we must add 0·01$^{mm.}$ for the periodic temperature dilatation, as explained before.

Therefore we have for the measurement of Kootenay base:

Wire 272 = 24001·11$^{mm.}$
Wire 273 = 24000·92$^{mm.}$

at the temperature 15° C. under a tension of 10 kg. on October 21, 1909.

Principle of Measuring.—The general principle followed in measuring is to find the number of times that a standard measure of length may be laid off along the line to be determined, marking the consecutive lengths as accurately as possible. The principle adopted by the International Bureau for measuring with invar wires, is the converse method, or in other words, to lay down courses having a certain approximate length, then to

measure accurately the length of these courses. This latter method is obviously the more precise.

The apparatus consists of twenty-four metre invar wires, having graduated end scales, a series of moveable tripods, clinometer accessories for reading the slopes of successive courses, and thermometers for recording temperature, besides such auxiliary instruments as pickets, level, levelling rods, aligning telescopes, plumb-bobs, &c.

Moveable Tripods.—Figure 4 shows a moveable tripod, the wooden frame A, having in its top a circular opening through which passes a smaller cylindrical metallic tube, B, which is

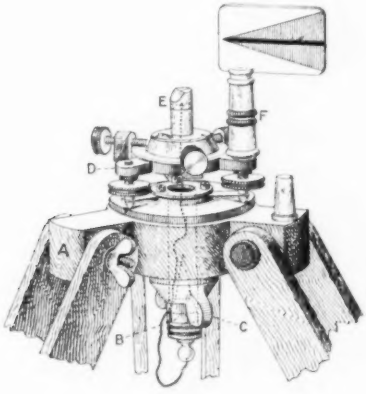


FIG. 4.

capable of a lateral displacement of several centimetres and may be fastened tightly to the wooden head by a thumb screw, C. The upper plate, D, bears three levelling screws held to the levelling plate by three springs. The datum mark, E, is also capable of a lateral motion by three horizontal screws, and carries a small level on its plate. The top of the datum mark is composed of a hard white alloy which will not oxidize. The cross forming the datum mark is of an ingenious design, having a bevelled edge, cut at the same angle as a cross-section of the end

scales, and permits the graduations to coincide with the horizontal plane of the datum mark. A plumb-bob, when not in use, screws into the tube, B, as in the figure, and the string passes through the hollow tube to a point directly under the cross of the datum mark. By means of this plumb-bob a definite point on the ground can be quickly and accurately transferred to the moveable datum mark. In the measurements of the Kootenay base, however, the transference was generally made by transit instrument.

The tripods, of which from six to eight are used, are set in position at approximately twenty-four metres apart, the alignment being made by small telescopes expressly intended for that purpose, or if hubs and tacks are set beforehand, the tripods can be fixed by means of the plumb-bobs.

A target, F, is placed on a vertical gudgeon beside the datum mark. On it readings of the slope are made with a small level hereinafter described. The flag is coated with white enamel, and in the apparatus devised by the International Bureau, the mark to be read upon was a horizontal black line six mm. wide. An improvement was made to these targets by painting a red triangle as in the figure. A better bisection can be made on the apex of the angle, and the red color assists greatly in rapid and precise reading.

Slope.— The difference in slope between successive tripods is measured by means of a small level shown in figure 5. The level replaces the flag on the upright gudgeon, the centre of the telescope being at the same height as the apex of the red target. At the focus of the object glass for a distance of twenty-four metres is a photographic scale etched on glass, the graduations being so spaced that one division covers twenty-four mm. at a distance of twenty-four metres, that is, reads a slope of one-tenth of one per cent. or ·001 in terms of the tangent. Readings are estimated to one-tenth of a division, or ·0001. Forward and backward readings are taken at each portée, or course, thus eliminating error of collimation.

On the Kootenay base, slopes up to five per cent. were read directly on the flags of the moveable tripods. Greater slopes than five per cent. were measured with the assistance of a long auxiliary rod, which when reading an ascending, or positive grade, was hung on the forward tripod with its flag close to the ground. By means of this rod the readings of the slope were reduced three per cent, and only the aplanatic part of the lens used. In reading negative or down grades, the auxiliary rod was placed above the low tripod, and the readings thus reduced five per cent. Wherever several slopes greater than five per cent were encountered, the heights of the end tripods above the hubs were measured with a tape, and by means of auxiliary levels with a transit the relative heights of the hubs were determined. The intermediate slopes read with the level were thus checked, and a close approximation obtained.

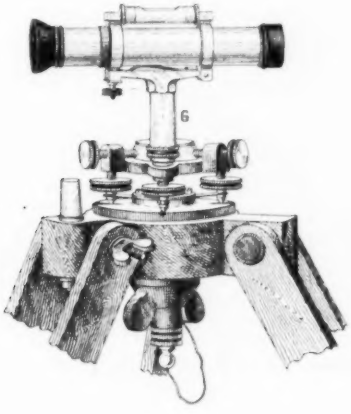


FIG. 5.

The level constants of the photographic scale were determined by sighting on a vertical rod placed at twenty-four metres. Numerous readings were taken under different weather conditions to allow for irregularity of light and refraction.

The correction for slope is made up of two parts. One is dependent on the horizontal projection of the straight line joining the tops of the tripods; that is $l\,(1-\cos.\ \alpha)$. This correction is given in table IV. in terms of tangent α for a slant length of twenty-four m. The table has been elaborately constructed up to ten per cent and may be quickly applied. In the last column of the table is also given the value of $l\,(1-\cos.\ \alpha)$ for a length of one metre. When the distance between two successive tripods differs from twenty-four m. by an appreciable amount, such as from ten to fifty mm., the correction for slope as applied directly from table IV. must itself be modified by the small correction for the said excess or deficiency.

The second correction for slope (table V.) is due to the fact that when the ends of the wire are not at the same level the curve ceases to be symmetrical, or a true catenary. The correction for this deformation in the curve is a function of the slope and although very small, cannot be neglected as it is always in the same sense, that is, positive.

Tables IV. and V. are to be found in the appendix of 'La Mesure Rapide des Bases Géodésiques,' fourth edition.

In the first chapter of the same book may be found an exhaustive mathematical discussion on the theory of measuring with a stretched wire, with the alterations which take place in the catenary when the tension is changed by even a small amount, either by friction or by changes in terrestrial gravity.

The difference between the effects of terrestrial gravity at Sèvres, France, where the wires were standardized (latitude, 48° 50′ N.; elevation, 184 feet) and at the Kootenay base (latitude 51° 04′ N.; elevation, 2,700 feet) is so small that the resulting change in tension of the ten kilogramme weight does not effect an appreciable alteration in the length of the wires.

Tension Tripods.—The wires are stretched for measuring by submitting them to a constant tension of ten kg., which is applied by means of weights suspended and hanging freely from window-sash cord passing over ball-bearing pulleys. The pulleys are supported by tension tripods as shown in figure 6. During

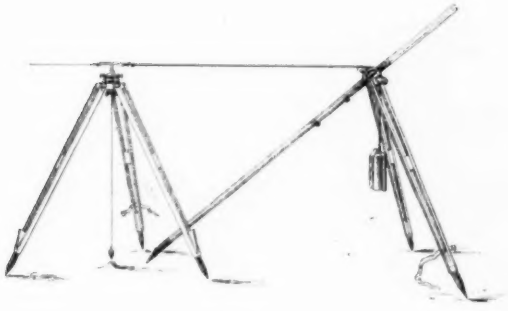


FIG. 6.

the measurements each tension tripod is placed in position by a man carefully drilled, and should be in the direct line of the base, and at such height that the graduated scale comes to within two or three millimetres of the datum mark. The ring at the end of the wire is attached to the tension cord by means of a hook and a snap and swivel.

Readings on the Wire.—An observer at each end of the wire reads the position of the datum mark on the graduated scale, pressing the latter with a gentle lateral motion against the datum mark. The scales are graduated in millimetres and readings are estimated to tenths. At least five readings are made at each end for every portée. The two scales are graduated in the same direction so that the reading at one end is always positive, and at the other is negative. The difference between the two readings gives the excess or deficiency from the true value of the wire. The readings in a set should rarely differ by more than 0·2 mm., a discrepancy greater than 0·3 mm. denoting an error in reading. In such a case the recorder orders extra readings to be made. Every so often the wires are reversed in direction end for end, or the observers interchange their positions, in order to eliminate personal equation, the observer at the positive end then making negative readings and *vice versa*. At each portée the readings are made on different portions of the scale, one

observer alternately shoving and pulling the wire, gently, but firmly, thus eliminating tensional friction in the pulleys or other accidental sources of error.

A tabulated form is used for all records and computations at each portée, a specimen page of which is here shown.

Triangulation Base Measuement — Invar Apparatus — Records and Computations

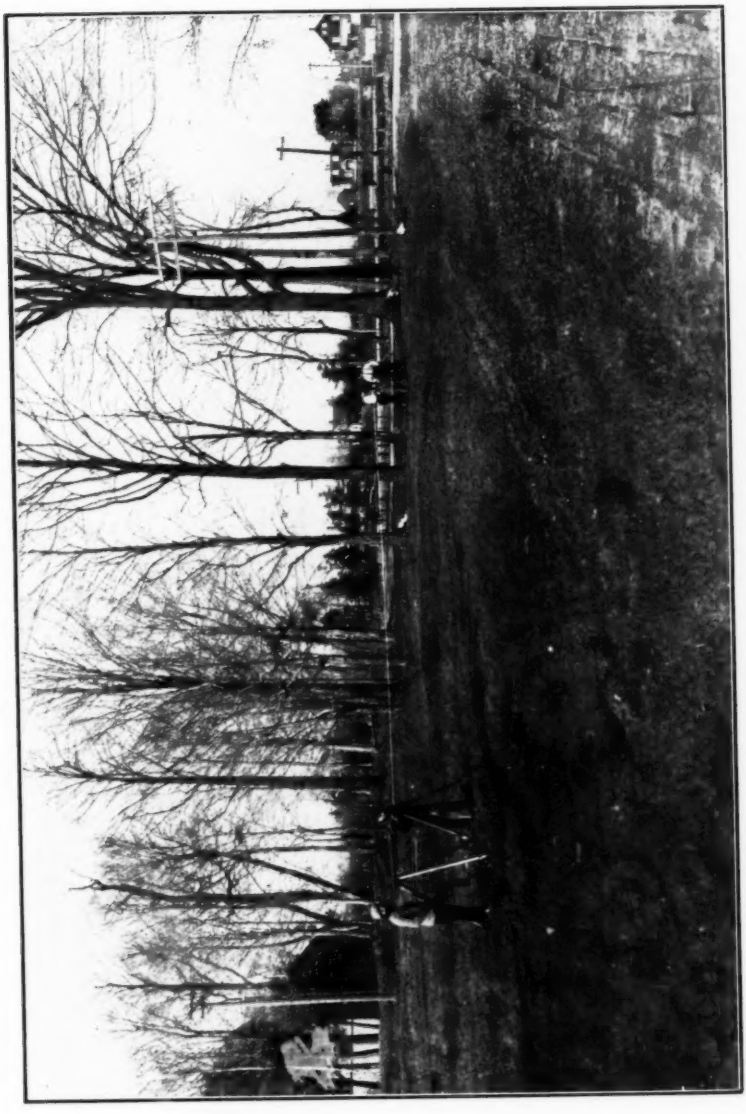
Recorder, Carson.
Observers, (Rear (+), Carson.
(Front (−), de la Condamine.

Portée No. 278.
Date, Nov. 2, 1909.
Time, 10.30 A.M.
Direction, Southerly.
Weather, Calm, Cloudy.

Readings							Slope (Tangent)		Temperature	
	Wire No. 272			Wire No. 273			Forward	Back		° C.
No.	Rear (+)	Front (−)	R − F	Rear (+)	Front (−)	R − F	+ 0406	− 0407		7·2
							0406	0407		7·8
			mm.			mm.			Mean . . .	7·5
1	42·0	21·3	+ 20·7	39·6	18·8	+ 20·8	Mean	+ 04065		mm.
2	59·0	38·4	20·6	46·4	25·6	20·8	Level Cor.	− 0003	Corr.	
3	36·7	16·0	20·7	62·8	41·8	21·0			(Table	
4	50·9	30·2	20·7	46·0	25·1	20·9		+ 04035	III)	+ 0·021
5	32·8	12·1	20·7	58·3	37·4	20·9		mm.		
							Cor. Tab. IV	19·465		
								·048		
								19·513		
								·016		
								19·529		
							Cor. Tab. V	+ ·005		
	Mean		+ 20·68	Mean . . .		+ 20·88	Total Corr. (−)	19·524		

	Wire No. 272	Wire No. 273
	mm.	mm.
Value of wire at 15° C.	24001·11	24000·92
Correction to 7°·5	+ 0·021	+ 0·021
Sum	24001·131	24000·941
Readings	+ 20·68	+ 20·88
Sum	24021·811	24021·821
Correction for Slope	19·524	− 19·524
Value of Portée	24002·287	24002·297

PLATE III.



THE INVAR BASE LINE INSTRUMENT

KOOTENAY BASE

Kootenay base controls the complete network of the triangulation survey in the railway belt, British Columbia, from the summit of the main range of the Rocky Mountains westward to the Cascade range.

The base lies in townships 19, ranges 19 and 20, west of the fifth meridian, on the right or easterly side of Columbia river, British Columbia, about twenty-one miles southeasterly from the town of Golden.

By means of three secondary stations the base is projected to the main triangulation, connecting with primary stations 17, 20 and 21, the simplicity and rigidity of the projection being almost ideal.

The approximate mean longitude of the base is 116° 39′ W; the mean latitude is 51° 04′ N approximately; the mean elevation is 823 metres above sea-level; the mean bearing is 309° 08′.

The length of the base, reduced to sea-level, is 8565·5735 metres.

Station A, marking the southerly end of the base, is 14·62 chains west, and 0·50 chains north of the wooden post marking the quarter section corner on the east boundary of section 16, township 24, range 19.

Station B, marking the northerly end of the base is 20·53 chains west and 12·28 chains south of the iron post and mound marking the northeast corner of section 35, township 24, range 20.

The end of the base, or geodetic point, at station A is the intersection of a pair of fine lines at right angles to each other, stamped in the head of a brass bolt six inches long and three-quarters of an inch in diameter with a flat head one and one-half inches square. This bolt is set in concrete three feet beneath the surface of the ground and is covered with loose earth. The head of the bolt also bears the letter A stamped upon it. There is no surface mark, except four iron reference bolts fifteen inches long and one inch in diameter which bear north, east, south and west respectively from the geodetic point, and are each distant three feet from it.

Station B is similarly marked except that the bolt bears the letter B stamped upon its head.

The base line skirts the westerly edge of the Beaverfoot range of mountains close to the bottom lands of Columbia valley. It crosses the Government wagon road no less than ten times, and also intersects the surveyed line of the projected Kootenay Central railway at several points. The base runs mostly through uncleared land covered with second-growth poplar and birch, crossing also several cultivated fields, and through occasional patches of spruce and fir averaging eighteen inches. The line was cleared of all timber, grass and brush for a width of six feet, large stumps being sawn off level with the ground. Beginning

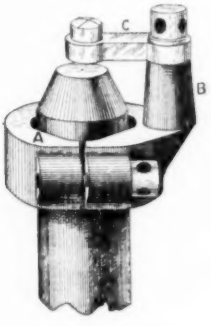


FIG. 7.

at the northerly end of the base, hubs twenty-four metres apart were set with a standard chain supplied by the makers of the base apparatus. This chain which is composed of twisted wire strands, was found to be unsatisfactory, as its length varied considerably with the temperature. The chain also soon became twisted and kinked with repeated windings and unwindings on the reel; and when the measurements were afterwards made with the invar wires the distance between some of the hubs differed from twenty-four metres by as much as fifty mm. Tacks

were placed in the hubs, the alignment being made with an ordinary four-inch transit. A forward line was run, sighting being made on the signal at station A, hence the errors of alignment were very small. The hubs were set along the whole length of the line and the southerly end of the base as previously established was changed and set at an integral number of twenty-four metre stretches. This change was necessary as only twenty-four metre wires were available for measuring, although with auxiliary wires of say four and eight metres any short distance can be conveniently determined.

The base was divided into six sections by means of controlling datum marks supplied with the apparatus. A cut of one of these datum marks is shown in figure 7. It consists of a round iron peg, pointed at one end, about eighteen inches long and one and one-half inches in diameter, which may be driven firmly into the ground. The collar A, which is fastened near the top of the peg by capstan screws, has a vertical gudgeon B, which again bears a revolving horizontal arm C. The end of this arm carries a small cross which serves as a datum mark. By the double motion of the two sets of screws this cross can be set very accurately on line, and within several millimetres of the desired longitudinal distance. It is not necessary to fix the datum mark accurately for distance, as, once it is in place, the distance to and from it is measured by setting a tripod accurately over it.

By dividing the base line into sections in this manner, six closing checks on the measurements were obtained, each section being considered separately. In determining the probable error of the adopted length of the whole base the probable errors of each section line were combined. The base was divided according to the configuration of the ground, each section being about the length covered in a day's work.

The base was measured in a northerly direction with a single wire, Nos. 272 and 273 being used at alternate sections. A complete double measurement was also made in a southerly direction using both wires. The method of using two wires is somewhat slower,

but serves to check the relative lengths of the wires, mistakes in reading and other sources of error.

The weather during the measurements was exceptionally suitable for this work. The days were mostly cloudy, with rain at night. The range of temperatures on some days was only about five degrees, 3° C to 8° C, with both rising and falling temperatures. On three days the weather was clear and the temperature rose from 3° C to 20° C, falling again to 7° C in the afternoon. Calm weather prevailed with occasional light winds, but not of sufficient freshness to disturb the wires. On two days rain fell during the measuring, but it is not thought that the sag of the wires was appreciably increased by the weight of the clinging rain-drops.

The distribution of the staff of seven engaged in the measurements was as follows: one man setting tripods over the hubs, one porter carrying tripods from rear to front, one man at each of the two tension tripods, two observers, one of whom acted also as recorder and leveller, and one porter carrying an end of the wires in lieu of the observer who performed the levelling. The work would have been materially expedited had a competent man been available to take the levels, this duty falling on one of the observers whose manifold duties retarded progress. Before commencing the measuring, the party was drilled with a practice wire until all became thoroughly familiar with the work, and acted together as a team with preconcerted signals. Before the completion of the base a speed of four hundred metres per hour was attained, when using one wire, which is indeed satisfactory, considering the nature of the ground on a base line in the Rocky Mountains.

Results of Measurements.— The results of the measurements of the Kootenay base have been tabulated in the accompanying table.

The second standardization of wires 272 and 273 showed that the latter wire had responded almost perfectly to the curve in figure 1, and M. Guillaume suggested that the measurements

with wire 273 should be taken as correct and the measurements with wire 272 as a check. Consequently the observed measurement obtained with wire 273, viz.: 8,566,677·829 millimetres has been adopted for Kootenay base. The error of this value due to

TABULATION OF MEASUREMENTS OF KOOTENAY BASE

Section	Portees	No. of Portees	Direction of Measurement	Date 1909	Temperature Range	Mean Temp.	Weather	Wire No.	Length of Section	
									mm.	mm.
I	1-60	60	N	Oct. 21	3 to 20	12	Calm, cl'dy to fair	272	1,441,007·529	1·832
			S	Oct. 22	7 to 14	10	Calm, cloudy, with	272	1,441,005·697	
			S	Oct. 22	" "		occasional breeze	273	1,441,007·307	
II	61-109	49	N	Oct. 23	3·4 to 7·5	6	Calm, cloudy, rain	272	1,176,324·003	0·875
			S	Oct. 25	2 to 13	9	Calm, cl'dy to fair	272	1,176,323·128	
			S	Oct. 25	" "		" " " "	273	1,176,323·188	
III	110-181	72	N	Oct. 26, 27	3 to 20 to 14	12	Calm, cl'dy, light	273	1,728,535·610	2·548
			S	Oct. 26	6 to 12 to 0	7·5	Calm, cl'dy [wind	272	1,728,537·238	
			S	and 28	" " "		Calm, foggy	273	1,728,538·158	
IV	182-223	42	N	Oct. 29	9 to 20 to 9	13	Calm, cl'dy to fair	273	1,007,437·097	1·129
			S	Oct. 30	6 to 11 to 3	7·4	Calm, cloudy, oc-	272	1,007,437·456	
			S	" "	" " "		casional breeze	273	1,007,438·226	
V	224-282	59	N	Nov. 1	3 to 7 to 4	6	C'lm, cl'dy, oc. br.	272	1,414,993·029	0·865
			S	Nov. 2	6 to 8 to 6	7	Calm, cl'dy, some	272	1,414,993·894	
			S	" "	" " "		showers	273	1,414,994·824	
VI	283-357	75	N	Nov. 3	5 to 10 to 5	7	Calm, cloudy	273	1,798,377·308	1·182
			S	Nov. 4	5·5 to 15 to 2	7	Calm, cl'dy to fair	272	1,798,374·814	
			S	and 6	" " "		Calm, fair	273	1,798,376·126	

Total number of portees = 357

	mm.
Length of Base (with wires 272 and 273 used at alternate sections)	= 8,566,674·576
" " " with wire No. 272	= 8,566,672·227
" " " with wire No. 273	= 8,566,677·829

At M. Guillaume's suggestion greater weight has been given to wire No. 273, and the value of the base as determined with this wire has been adopted as the true value of the base

	mm.
	= 8,566,677·829
Correction to ocean level	= − 1104·3
Final value of base (in mm.)	= 8,565,573·5

Probable error of absolute length of wire 273 = 0

Probable error due to measurements =

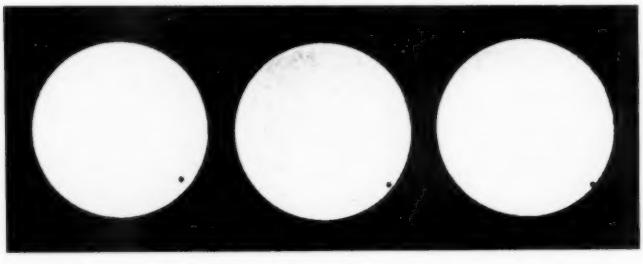
$$\frac{1}{2}\sqrt{\frac{357}{6}\left(\frac{1\cdot832^2}{60}+\frac{0\cdot875^2}{49}+\frac{2\cdot548^2}{72}+\frac{1\cdot129^2}{42}+\frac{0\cdot865^2}{59}+\frac{1\cdot182^2}{75}\right)} = \pm\ 1\cdot8 \text{ mm.}$$

comparisons is inappreciable. The error due to measurements (*i.e.* slope, temperature, readings on the wires, setting of tripods, etc.) has been determined as follows: The difference between the two lengths of each section of the base obtained by the same wire is due to measurements only. These differences for each section have been combined to obtain the probable error of the whole base due to the measurements, each section being given a weight corresponding to the number of portées it contains.

The length of the base has been reduced to sea-level, the correction being a function of the measured length, the elevation above the sea, the latitude, and the bearing. The correction for this base is 1·1043 metres.

REV. T. W. WEBB, M.A.

GEORGE H. WITH, F.R.A.S.



2.45 2.30 2.15 p.m.

PHOTOGRAPHS OF THE TRANSIT OF VENUS,
December 6, 1882, taken by Samuel Cooper, of Charminster, Dorsetshire, with a 9-inch Reflector.

A PLEA FOR THE REFLECTING TELESCOPE

By G. Parry Jenkins

I HAVE taken upon myself the responsibility to-night of making a plea for the reflector because I am addressing a Society whose members are composed primarily of amateur astronomers, to whom the possession of a good telescope with which to study the wonders of the heavens is an actual necessity. I well know that a great difference of opinion exists in the minds of observers as to the relative merits of the two classes of instruments in common use, viz.:—Refractors and Reflectors; and having had personal experience extending over a number of years with both kinds, you will, I am sure, bear with me when I attempt to lay before you some of the peculiar advantages of the latter, together with reasons for this choice.

Last year we celebrated the tercentenary of the invention of the telescope with which Galileo observed the heavens, but as I need hardly point out that was the refractor constructed in 1609, for the reflector did not come on the scene until over fifty years later. Its appearance was due to the conviction in those days that opticians had reached the limit of their skill in the production of telescopic objectives, which at their best were all non-achromatic and whose color aberrations interfered so materially with good seeing.

It is interesting to note, in passing, the various attempts the old astronomers made to overcome this serious defect in their telescopes, but without success, the reason being that every lens is in reality a collection of prisms, and a prism shews everything bordered with rainbow hues.

The physicists of to-day, armed with the spectroscope, owe all the knowledge they possess of the heavenly bodies to this property which a triangular piece of glass possesses of splitting up a beam of light into prismatic colors, but the early observers

with the telescope tried every means in their power to get rid of this same fringe of color, as they were concerned only with visual observations.

With this purpose in view the definition of the primitive glasses was partially improved by increasing their focal length and, consequently, enlarging the image, while the color fringe of the objects viewed remained of about the same breadth. On this account these early telescopes grew apace until we find them measuring 100 feet in length. One was actually constructed 600 feet long but it proved too unwieldy to be utilized. In the hands of such men as Hevelius, Huyghens and Cassini many important discoveries were made, however, with these imperfect and very cumbersome instruments.

At this time the immortal Newton tackled the color problem of the refractor. It is true he also failed to correct it. Accordingly he turned his attention to some other way of solving the problem, and accomplished it by devising a new mode of telescope, called the reflector, which shewed objects in their true light, and eliminated all the tantalizing prismatic colors that had so perplexed the old observers. So the Newtonian reflector first appeared in the year 1668. In Sir Isaac Newton's hands it was only a few inches long, but to-day some of the leading telescopes of the world are built upon this principle. In this case the image is formed by reflection from a concave mirror and not by transmission through an object glass as with the Refractor. The image thus formed is then magnified by the eye-piece in the ordinary way.

The four leading forms of reflecting telescopes are known respectively as:—

The Gregorian, after Dr. James Gregory, who actually constructed this particular kind in 1663.

The Newtonian, after Sir Isaac Newton, who devised it.

The Cassegrainian, after the well known Frenchman, Cassegrain, who invented it in 1672.

And the Herschelian, after Sir William Herschel, who so successfully adopted this special kind of instrument although he

was not the inventor of this type. This honor belongs to LeMaire, who first constructed it in 1728.

In the survival of the fittest, which is true in the realm of telescopes as well as other spheres, the Newtonian is the most popular reflector of the various kinds in use at the present time, and it is this class of reflectors I wish more particularly to draw your attention to this evening.

Let me, however, in the first place trace briefly the history of the reflector as it was being developed in the hands of some of its most enthusiastic advocates, and see some of the marvellous results that were achieved by its users to garnish the store of astronomical knowledge which is ever increasing as age after age rolls on. Here, again, we find that the amateur has worthily filled his place side by side with the professional astronomer and that each by his unswerving devotion to the science we cultivate in common deserves our meed of praise.

Every mirror that was used in the construction of these telescopes, previous to fifty years ago, was composed of a copper alloy (usually 126 parts of copper to 59 of tin) called speculum metal. It followed as a natural consequence that the surface, despite every care and attention, would sooner or later corrode after coming in contact with the night air. On this account the figure was in constant danger of being spoilt, when its surface had to be repolished; and as the parabolic curve was difficult to attain at all times, it thus happened that when once the mirror deteriorated it often became a tedious and hard task to bring it back to its original defining quality. As we can readily understand, this was one of the most serious drawbacks to the permanency of such an instrument, but nothing seemed to daunt the efforts of the pioneers of observational astronomy.

It was in 1774 that a young musician named William Herschel, then residing at Bath, made a 5-inch reflecting telescope, and how little the world of astronomy realized the star of first magnitude that had arisen on the horizon by this event! Henceforth the progress of the reflector was by leaps and bounds. Herschel made about 200 mirrors himself, his greatest effort cul-

minating in the famous 4-foot reflector with which he discovered two satellites of Saturn, and made many other epoch-making discoveries.

The telescope with which Sir William Herschel discovered the planet Uranus in 1781 was of 6 inches aperture only, and I remember, as a boy, looking at it with admiration in South Kensington Museum.

In 1845 Lord Rosse completed his 6-foot reflector at Parsonstown, and the confines of the known universe were indefinitely enlarged thereby. As regards size, this monster telescope is still unsurpassed. The tube is 56 feet long, 7 feet wide and the great metallic mirror alone weighs 4 tons.

The celebrated optician Steinheil, in Germany, first hit upon the idea, in the year 1856, of utilizing glass instead of metal as hitherto for telescopic mirrors, and the following year Léon Foucault, in France, independently made the same suggestion. Henceforth the silver-on-glass reflector came to stay.

In the early sixties George Henry With, a schoolmaster in Hereford, turned his attention to making these new telescopes. His work was soon brought into notice by the Rev. T. W. Webb, the well-known astronomer, who lived in the same county, and had marked his progress from the start with much satisfaction.

In November, 1865, we find the Rev. Mr. Webb writing regarding this pioneer as follows:—"Mr. With is going on admirably with his specula. Those of 6½ inches and 5½ foot focus have, I hear, most marvellous definition. He has just sold a splendid thing of 10⅛ inches, the performance of which greatly delighted me."

The Rev. T. W. Webb's venerable father now presented his son with one of With's 9½-inch mirrors, and the grand work performed with it is recorded in many a page of "Celestial Objects."

These "With" mirrors then became world-famous, and observers of the greatest reputation often chose them in preference to the refractor.

Nathaniel E. Green used one of 13 inches aperture in his

classic study of Mars at Madeira in 1877, and afterwards an 18 inch in his observations of the belts and markings of Jupiter. This latter is described by Mr. Green in Vol. xlix., Part 2, of the *Memoirs* of the Royal Astronomical Society for 1887-89 as "a superb mirror figured by George With of Hereford."

Residing, as I did, for ten years in the city of Hereford I numbered Mr. With as one of my closest friends, and many a time have watched him grind his mirrors. How delicate and tedious an operation it was can readily be inferred from the fact that a deviation of only one thousand part of an inch from the true parabolic curve would spoil the mirror.

In reference to the Rev. T. W. Webb's appreciation of the reflectors turned out by G. H. With the following unpublished letter in my possession, reproduced on pages 64-66, is most interesting.

In comparing refractors and reflectors the principal reasons of the preference for the latter amongst amateur astronomers in particular may, I think, be summed up as follows: — Absolute achromatism; the visual and actinic rays being brought to the same focus, this instrument is equally good for photography as for observing; the horizontal view of all objects looked at; and the price only a fraction of a refractor of same size.

Prebendary Webb, the author of "Celestial Objects for Common Telescopes," whose qualifications to speak with authority on this subject, no one will question, states in the above work:—

"An achromatic, notwithstanding the derivation of the name, will show color under high powers where there is much contrast of light and darkness. Reflectors are delightfully exempt from this defect; and as now made with specula of silvered glass, well deserve, from their comparative cheapness, combined with admirable defining power, to regain much of the preference which has of late years been accorded to achromatics."

In the *English Mechanic and World of Science*, for June 20, 1879, W. S. Franks, the well-known observer, gives a very careful comparison between an achromatic refractor and a reflector side by side, and concludes that the light of a 6½-inch silvered

Hardwick Vicarage. Hay. 10 Dec '81.

My dear Mr Webb,

I enclose you what I promised, and what I hope may answer your purpose. — Flammarion's list goes back much further, even to the first measure, and you shall have any you like — but I thought since 1870 would probably be sufficient from an account of the Washington telescope. I have just received. It appears that it has divided a pair at only 0".23, as the ultimatum known, so that our friend γ^2 is beginning to run it very hard — by my elongation, of which I am pretty certain, says a good deal for the $9\frac{1}{3}$ inch by Dawes's formula (Cel Obs p 7) it could not be expected to divide below 4".9 (pretty well, I think, to do what it does. But with my old eyes! Do 2 forenen under 500, considerably. —)

I think the last three tolerably favourable nights have a good deal dispated any idea that my eye has much deteriorated

FACSIMILE OF LETTER WRITTEN BY T. W. WEBB TO G. H. WITH, (1881). [*Continued on next two pages.*]

I have seen things so very much better
than for months previously that it is evident
how much atmosphere has to do with it
On Wednesday & Thursday I suspected Encke's
division & saw the gauze ring very fairly
And Jupiter has a much sharper limb
Mars [illegible] is sharp enough. but details so fee
ble. I do not know which may be in fault
there

Mess Beale talks about not going beyond
£30 without authority of Council — Utter as
the supposition of the sale of them forms a-
chromatics — a small (± 3 inch) but very good
one — for £12 to 18. — Which I think they
will not get readily. 'Tis a queerish sta-
tripod, too. — So I fancy these ideas
stand over. —

I must close, with kindest regard

Yours most sincerely

T. W. Webb

γ^2 Andromedæ –

(from Flammarion's Catalogue)

1870	18	– 0″64	– 0Σ
–	71·01	– 0″61	– Druèr
–	71·24	– 0″50	– Dembowski
–	72·19	– 0″60	– 0Σ
–	72·90	– 0″61	– Brunnow
–	73·17	– 0″67	– 0Σ
–	73·81	– 0″50	– Wilson & Seabroke
–	73·94	– 0″46	< Gledhill
–	74·93	– 0″56	– Gledhill
–	75·14	– 0″62	– 0Σ
–	77·05	– 0″48	– Schiaparelli
–	77·11	– 0″38	– Hall

(from Washington Obsr with 26 inch Prof. Hall – power 888.)

1877	104	– 0″35
—	109	– 0″38
—	112	– 0″37
—	115	– 0″37
—	117	– 0″43
1880	037	– 0″33
—	039	– 0″35
—	045	– 0″28

speculum is equivalent to that of a 5-inch object glass. I formerly owned the fine 5-inch refractor by W. Wray with which this instructive comparison was made.

The introduction of the silver-on-glass mirrors came as a boon and a blessing to many of those who, in Miss Caroline Herschel's language, "minded the heavens," but had hitherto been unable to gratify the natural wish to own a telescope.

If I am here found to be personal and reminiscent you will have to forgive me as it has been my privilege to know quite a number of observers in different stations in life who used the reflector, and from it derived their greatest pleasure and intellectual profit.

Astronomers in humble life have been many, and the harder the way to reach the stars the more determined appeared the aspirants to knowledge in almost every instance.

I will lay before you a case or two in point.

In the quaint old village of Charminster, in the south of England, lived a bricklayer by trade named Samuel Cooper. Of a contemplative and enquiring turn of mind, astronomy and its marvels appealed strongly to him from youth upwards. After studying the various popular books on the subject he could lay his hands upon, he determined at last to make himself a telescope. He succeeded so well that he became quite an expert on the construction of such instruments, and under the *nom de plume* of "The optical Bricklayer" enriched many a page of *The English Mechanic* with his self-acquired knowledge on telescope making.

In the early eighties I visited this worthy old astronomer in his little thatched cottage in Dorsetshire, and saw his 9-inch reflector with which he photographed the Transit of Venus, on December 6, 1882. Clouds interfered with many of the elaborate preparations that had been made all over England to witness this rare event, but at 2.15, 2.30 and 2.45 p.m. Samuel Cooper had the intense satisfaction of seeing and photographing the phenomenon which so many missed. (Plate IV.) He very kindly presented me with the original negatives, and as no member of the Royal Astronomical Society of Canada can possibly expect

to have the chance of taking such a photograph until the 7th of June, in the year 2004, I have decided to hand over these precious negatives, for safe keeping, to our Society. By the way a namesake of mine, Henry Jenkins, lived to the ripe old age of 169 years, and, as you know, this is authenticated, but for anybody to be obliged to wait 94 years hence for another opportunity of photographing the transit of Venus is, to say the least of it, like "Hope deferred, maketh the heart sick."

Another astronomical genius was born in the fair Isle of Anglesey, in 1818, not far from the historic spot where the Roman General Suetonius massacred the Druids of old. He bore the very ordinary name of John Jones, and was brought up as a farm laborer. If compulsory education had been in vogue in Great Britain in those days I have not the slightest doubt John Jones would have been occupying a professor's chair in one of our leading universities. As it was, his thirst for learning was baffled at every turn, but still he triumphed.

Dr. Samuel Smiles, of "Self-Help" fame, makes use of this very personage in his work entitled "Men of Invention and Industry," published in 1884, to show what perseverence can attain when the soul is aflame after knowledge and a telescope, and pays a glowing tribute to his accomplishments.

I had the honor of knowing John Jones intimately as I once lived in the Island of Anglesey, and many were the pleasant evenings we spent together in my own observatory and afterwards at his home looking through his great $8\,^{9}/_{16}$-inch reflector made by his own hands, and which he familiarly called "Jumbo." He told me that after receiving only twelve months' schooling he hired to a farmer. Being a Welshman, to acquire the English tongue was just like learning a new language to him, and this he accomplished almost entirely from books. After working some years with the farmers, he was employed by an itinerant Methodist minister, and when he had saddled his master's horse on Sundays he used to secrete himself in the library of the old divine and there, as it were, acquired by stealth his first knowledge of astronomy, for amongst his master's treasures was a

Welsh book on astronomy, being Dr. Thomas Dick's "The Solar System," translated into Welsh by Eleazer Roberts, of Liverpool. The lure of the skies held him spell-bound ever afterwards.

When about thirty years old illness overtook him, and he removed to Bangor, the centre of the great Welsh slate industry. He was employed at twelve shillings a week in counting slates or loading the ships in the harbor with the same. He now learnt navigation and mensuration from one who kept school for young sailors. The perusal of Sir John Herschel's "Outlines of Astronomy" and of his "Treatise on the Telescope" about this time set his mind on fire as he said. He conceived the idea of making a telescope, for he could not afford to buy one. His first attempt was one thirty-six inches in length, the tube being made of cardboard, and the glasses costing four shillings and sixpence only. With this he could see Jupiter's four moons, the lunar craters and a few double stars. He was delighted, but longed for a more powerful instrument. It was now he also began to study Greek, a friend having bought him a Greek Testament and a Greek Lexicon.

In the year 1868 he commenced the task of making a reflecting telescope, having, out of his scant earnings, bought a rough piece of glass from St. Helens, of 10 inches diameter. Now came the grinding and polishing to a spherical curve, all of which he did without a lathe by his own hands with the aid of emery and rouge. The mirror was then parabolized and silvered by George Calver. John Jones then mounted it in a wooden tube and stand all made by himself and its performance turned out to be very satisfactory. I well remember him telling me with what glee he had first seen the snow-cap on Mars through this instrument.

I also noticed amongst his treasures an equatorial head on a firm tripod stand constructed entirely by him. The declination and right ascension circles of this equatorial were unique. It is not too much to say, I believe, that they are the only examples of

the kind extant. They were constructed of slate and divided with mathematical accuracy into degrees and minutes.

John Jones also made a good 6-inch reflecting telescope, together with a spectroscope. In later years he could read the Hebrew Bible, and had achieved some fame as a local poet.

It was a singular pleasure for me to propose him as a member of the Astronomical Society of Wales, in 1895 — he was then 77 years old—and in the fourth number of the *Journal* of that Society I have contributed a sketch of his life.

So in counting slates by day and counting the stars at night this grand old man passed away in 1898, at 80 years of age, an inspiration to others (friendless and unaided as he was) to patiently surmount every difficulty in the attainment of one's desires.

In direct contrast to the two previous examples of "astronomy under difficulties," let me now dwell for a few moments on the career of one who was in affluent circumstances when he devoted his whole time and talents to the pursuit of the science. In this instance it was a case of the very best outfit that money could buy to further the cause of original research in the field of celestial photography. Isaac Roberts, of Maghull, Liverpool, procured a reflecting telescope of 20 inches aperture, in 1885, from the famous workshops of Sir Howard Grubb, of Dublin. Soon afterwards this instrument was mounted on the summit of Crowborough Hill, Sussex, and photograph after photograph of nebulæ, clusters and star groups were obtained, many of which have remained unequalled to this day. Two magnificent volumes, containing a selection of these photographs, were published in 1893 and 1900, and will remain a lasting memorial to the labors of this distinguished astronomer. I well remember the astonishment which his photograph of the great Andromeda Nebula (taken on October 10th, 1887) created amongst all observers of this well-known object. G. P. Bond, with the 15-inch refractor of the Harvard Observatory, had long ago noted two dark bands, or lanes as they were called in the nebula. I had often succeeded in seeing these same markings with my 8½-inch "With" re-

flector, and I considered the fact spoke well of the performance of my own telescope. To me this also exemplified Sir William Herschel's oft-quoted remark that a less optical power will show an object than was required to discover it.

When Roberts' photograph was exhibited it revealed for the first time the real structure of the great nebula. The dark bands referred to by Bond were found to be divisions between symmetrical rings of nebulous matter surrounding the nucleus according to Dr. Roberts own words, and thus the spiral character of this nebula was proved beyond doubt. A few days after this remarkable photograph was taken (just over 23 years ago) a copy was sent by Dr. Roberts to Professor Charles Pritchard, then Savilian Professor of Astronomy in the University of Oxford, who in turn sent it to G. H. With, of Hereford, in whose hands I saw it the day of its arrival. Mr. With had constructed a 15-inch reflector for Professor Pritchard, who was very proud of the mirror, but in referring to the photograph just taken by Roberts and the stars involved in the nebulosity he wrote, I remember, – "No amount of gazing through my 15-inch will reveal the stars easily seen on the photograph. The reason must be that the impressions received by the retina are only transient, while on the photographic plate they are cumulative."

It has never been made public, as far as I know, that W. S. Franks was the assistant photographer on Crowborough Hill, but posterity will, no doubt, yet give him credit as being Dr. Roberts' worthy coadjuter.

In an able article on "The Tercentenary of the Telescope," in the *Edinburgh Review* of January last, the writer, referring to Dr. Isaac Roberts' achievements, most appropriately says :—

"Mature judgment finds in his work two qualities altogether admirable—he pursued the less showy and more difficult objects which offer few attractions to the picture-maker, so that now, years after the two volumes were published, we may find in them photographs of things which are unobtainable elsewhere; and secondly, he gave with each photograph a precise statement of its orientation, the scale upon which it was reproduced, and the identification and position of selected stars appearing in it; obvious things to do, one might say, were it not that they are curiously rare, and the last unique."

I consider Samuel Johnson's dictum applies with special force to the observational astronomer — "He that enlarges his curiosity after the works of nature, demonstrably multiplies his inlets into happiness." Those who could endorse this saying as the result of using the reflector are many, and their names must recur to your minds as readily as to my own. The following and their instruments have become famous.

A. Stanley Williams, of Brighton, 6½-inch Reflector.

T. Gwyn Elger, of Bedford, 8½-inch Reflector.

W. F. Denning, of Bristol, 10¼-inch Reflector.

Edwin Holmes, of Hornsey Rise, 12¼-inch Reflector.

Scores of others might be mentioned.

I will, therefore, only refer to another instance or two that have come under my immediate notice.

Arthur Mee, the well known author of "Observational Astronomy," published in 1893, and other works, has constantly used for over 20 years an 8½-inch "Calver" reflector, and is as satisfied to-day with its defining power as when he purchased it. His drawings of the sun, moon and planets have frequently appeared in the *Journal* of the British Astronomical Association and other periodicals, and are excellent. The one of Jupiter from his pencil, which I submit for inspection, will bear out my statement.

No man has done more towards popularizing astronomy in the principality of Wales than Arthur Mee. He founded the Welsh Astronomical Society in 1894 and was its first president. From the commencement Mr. Mee has edited its *Journal*, and I am glad our Society continues to exchange publications with the sister society in gallant little Wales.

One of the most accomplished draughtsmen of the present day in delineating planetary details is Scriven Bolton, of Leeds. His "Note (illustrated with a plate) on the General Aspect of the Principal Markings on the Planet Jupiter during the Apparition of 1907-8," formed a feature of No. 3 of Vol. lxx., of the *Monthly Notices* of the Royal Astronomical Society published in January last. Mr. Bolton employs two Newtonian reflectors,

one by Calver of 18¼ inches aperture, and the other a With-Browning of 10¼ inches aperture.

I was fortunate in being presented, by this observer, with four beautiful lantern slides of some of his drawings of Jupiter and Saturn, colored by his own hand. At the close it will afford me pleasure in showing them to you. The one of the planet Saturn, taken on January 31st, 1909, received the gold medal at the Recent Franco-British Exhibition in London.

In America the reflector was condemned before it had been given a trial, but the proof of the pudding is in the eating you know.

With Christmas only a few days ahead of us I make use of this simile advisedly as at another time its truth might not come so near home to us.

About the year 1858 Henry Draper paid a visit to Lord Rosse, in Ireland, and saw the mighty reflector of Parsonstown. It can be said of him like Cæsar of old—"He came, he saw, he conquered." On his return to America Draper constructed a 15-inch reflector with which he produced a magnificent photograph of the moon four feet in diameter.

In 1865 followed a work that was published by the Smithsonian Institution and remained a standard on the subject for a number of years, viz.:—"Construction of Reflectors," by Henry Draper.

By 1871 Dr. Draper had erected a 28-inch silver-on-glass reflector, which was the largest in America at that time, and is to-day still in use at Harvard University.

A year later (1872) the first star whose spectrum was successfully photographed was Vega, by Henry Draper. Truly a wonderful achievement. In another sense it was the day of small things, but therein was laid the beginning of the great "Draper Catalogue of Stellar Spectra," published in 1900, and including the composition of over 10,000 stars.

In England the art of speculum grinding has, undoubtedly, reached its highest level in the hands of the famous maker George Calver, of Chelmsford, whose work is still unsurpassed.

About fifteen years ago a three-foot reflecting telescope belonging to the late Edward Crossley, M.P., Halifax, Yorkshire, and made by Calver, was presented to the Lick Observatory. On Professor J. E. Keeler becoming director of that institution in 1898 he immediately undertook, as his personal task, the photographing of the brighter nebulæ and star clusters with this instrument. His untimely death prevented, to a certain extent, the consummation of this project, but Vol. VIII. of the *Publications* of the Lick Observatory, published two years ago (and which can be examined in the Library of our Society) contains 68 specimens of celestial objects secured by this telescope. Nothing more beautiful in this line has probably ever been published.

Professor Keeler's own opinion of this reflector is worth quoting as taken from the *Astrophysical Journal* of June, 1900. "The mirror, the most important part of the telescope, has an aperture of three feet, and a focal length of 17 feet 6·1 inches. It was made by Mr. Calver. Its figure is excellent. According to the Foucault test, the illumination of the mirror is very uniform, while star discs, as seen in an ordinary eye-piece, are small and almost perfectly round."

One of the largest silver-on-glass telescopes in existence is the late Dr. A. A. Common's renowned 60-inch reflector built in 1889, and at present forming a part of the astronomical equipment of Harvard Observatory, to which it was transferred in 1904.

Dr. Common, of Ealing, usually gets the credit of figuring the speculum of this magnificent instrument, which has been used so effectively in celestial photography and measuring the light of very faint stars, but as a matter of fact (as pointed out by Arthur Mee in his "Story of the Telescope," published last year) it was Albert Taylor, Dr. Common's assistant, an amateur astronomer of great ability, and now one of His Majesty's Welsh Inspectors of Schools, who actually made the great mirror, —so honor to whom honor is due.

Almost the last word on my subject must be the bare men-

tion of G. W. Ritchey's elaborate work "The Modern Reflecting Telescope," published in 1904. If time allowed I might dwell upon the remarkable productions of Professor Ritchey, who makes, mounts and observes with his own telescopes — the largest being a 60-inch reflector, although a 100-inch is in contemplation — at the Solar Observatory of the Carnegie Institution at Mount Wilson and Pasadena, but Professor Chant, who was a delegate at the Conference of the Solar Union on Mount Wilson, this year, has very graphically given us an insight into what is being accomplished there, in our last September-October JOURNAL.

Here I must stop. The array of facts which I have laid before you of the success of the reflector in the hands of those who have made it their working tool, will I hope justify my plea for its continued use amongst astronomers, and more especially the ordinary members of astronomical societies such as ours.

MEETINGS OF THE SOCIETY

Annual Meeting at Toronto

The General Annual Meeting of the Society was held in the Rooms, 198 College Street, on January 10th, the President in the chair.

Reports from the Treasurer, Secretary and Librarian were received.

The officers for 1911 were declared elected as follows:

Honorary President, W. F. King, C.M.G., LL.D., Ottawa.

President, Professor Alfred T. DeLury, Toronto.

First Vice-President, Professor Louis B. Stewart, Toronto.

Second Vice-President, J. S. Plaskett, B.A., Ottawa.

General Secretary, J. R. Collins, Toronto.

Recorder, Lachlan Gilchrist, Toronto.

General Treasurer, Chas. P. Sparling, Toronto.

Librarian, A. Sinclair, M.A., Toronto.

Curator, Robert S. Duncan, Toronto.

Members of Council—Joseph Pope, C.M.G., Ottawa; G. Parry Jenkins, F.R.A.S., Hamilton; Rev. I. J. Kavanagh, S.J., D.Sc., Montreal; Rev. Dr. Marsh, F.R.A.S., Peterboro; Dr. A. D. Watson, Toronto; A. F. Miller, Toronto.

These with the Past Presidents and the presiding officer of each Centre constitute the General Council of the Society.

The General Annual Conversazione of the Society was held in the Physics Building of the University of Toronto, on the evening of January 17th.

President Falconer, of the University, occupied the chair and Professor DeLury, President of the Society, delivered the

Annual Address, choosing as his subject for this year "The Evolution of Worlds."* After the address a number of laboratory rooms of the Physics Building were thrown open to members and friends, and under the direction of Mr. Gilchrist and a number of assistants, various experimental exhibits were shown, illustrative chiefly of spectrum analysis, and Professor Chant exhibited on the screen a number of lantern slides made from the most recent photographs of celestial objects, after which light refreshments were served to the guests. This year's Conversazione was, probably, the most successful of these always interesting functions, that has as yet been held.

J. R. C.

AT TORONTO.

January 23, 1911.—The meeting was held in the large lecture room of the Chemistry and Mining Building of the University of Toronto.

The lecture of the evening was given by Professor R. G. Aitken, of the Lick Observatory, University of California, on "Life in Other Worlds." The lecturer gave a very clear and interesting account of the methods of investigation, and evidence for and against the theory that life exists on other planets, *i. e.*, life as we on earth know it. The presence of an atmosphere, of water in the liquid form and a moderate range of temperature are the necessary conditions for the existence of life. For the purpose of investigation the planets were divided into two classes, the larger planets—Jupiter, Saturn, Uranus and Neptune—and the smaller planets which have many points in common with the earth. The larger planets were considered briefly, and it was shown that the evidence adduced precluded the existence of life upon them. The terrestrial planets were considered individually, and it was shown that the evidence pointed to the conclusion that life did not exist on Mercury, that it was improbable that it existed on Mars, and in the case of Venus the evidence was too meagre. The investigations considered were those on the period

*The address in full appears in this issue of the JOURNAL.

of rotation, the existence of an atmosphere as considered from the kinetic theory of gases, the amount of light and heat received from the sun, the presence of water vapor as shown by the spectroscope and the presence of artificial markings on the planets.

A large and interested audience was present and the lecture was received with close attention and keen appreciation.

February 7. — Professor L. B. Stewart gave a lecture on "Comets," with particular reference to Halley's Comet. The development of the methods of obtaining the orbits of comets was outlined, an account being given of the work of Newton, Encke, Laplace, Gauss and others. Professor Stewart also gave a detailed account of his own measurements made with a geodetic theodolite in determining the elements for a parabolic orbit and an elliptic orbit, and outlined the various correction factors and method of determination of them.

February 21. — The meeting was held in the Physics Building of the University of Toronto.

Professor J. C. McLennan, of the University of Toronto, gave a lecture on "The Ether." The necessity for the conception of the ether was outlined by Newton's deductions from Kepler's laws, and the transmission of energy through space. Experiments in magnetic and electrical attraction were shown to illustrate this, and also vortex rings showing mutual repulsion. Illustrations were given of the dependence of mass on velocity, and calculations were made of the amount of energy accompanying an electron in motion, of the radius of the electron and of the density of the ether. The lecture was received with close attention and deep interest and a hearty vote of thanks, moved by Mr. J. A. Paterson, seconded by Mr. W. B. Musson, was tendered to the lecturer.

L. G.

AT OTTAWA

December 9, 1910 at the Observatory. — The paper of the afternoon was given by Mr. R. M. Stewart, M.A., his subject being "Systematic Errors in Estimating Relative Position of Wires." Mr. Stewart first showed the relation of this paper to

a former paper given by him, (May 13, 1910), entitled "Personality in Micrometer Work," and explained how the measurements were made by means of the reversing prism. The examples discussed were:—

Setting on one wire with two.

Setting on a circular dot.

Setting on a graduation.

Setting two wires between two others.

The setting of one wire on another was not discussed, it being considered a very poor setting. The systematic error of setting the collimators in meridian circle work was then discussed; also the effect on clock errors and deduced star places. A comparison of star places from different catalogues of stars at different latitudes confirmed the suggestion that the differences might be due to such errors.

The paper, which was one of great interest and of practical importance, provoked considerable discussion, after which the meeting adjourned.

December 15. — The annual meeting for Ottawa members of the Royal Astronomical Society of Canada was held in the Carnegie Library, Dr. Klotz presiding.

The minutes of the previous annual meeting were read and adopted.

Reports of the Secretary and Treasurer were read and adopted. It was moved by J. S. Plaskett, seconded by R. M. Stewart, that the Secretary be instructed to transmit a memorial to the General Secretary of the Society at Toronto, stating that in the opinion of this meeting it would be in the best interests of the Society to authorize the local treasurer to receive subscriptions and give official receipts for the same (Carried).

Mr. Thos. Fawcett was elected a member of the Society.

The election of officers for 1911 resulted as follows:—

Chairman, J. S. Plaskett,

Vice-chairman, R. M. Stewart,

Secretary, Carl Engler,

Treasurer, C. C. Smith,

Councillors, W. E. Harper, F. A. McDiarmid, J. J. McArthur.

After an informal discussion as to the work of the Society, and a few remarks by Dr. Klotz, the retiring chairman, the meeting adjourned.

January 12, 1911, at the Observatory.—Mr. R. M. Stewart presided while Mr. J. S. Plaskett gave an address on "Notes from two Recent Astronomical Gatherings."

The first gathering, from August 17 to 19, 1910, at Harvard Observatory, of the Astronomical and Astrophysical Society of America, was arranged so that those attending might travel across the continent together to the Solar Conference at Mount Wilson in California. Mr. Plaskett gave a summary of the most important papers at each meeting. At the first were notable papers by Professor Campbell of Lick Observatory on "Some Preliminary Results Deduced from Radial Velocities of Stars," in which he gave the values of the apex of the sun's way and the velocity of the solar motion, and by Joel Stebbins on "The Selenium Photometer." At the Solar Conference the subjects of a new system of standard wave-lengths, of sun-spot spectra, of spectroheliograph work, of the solar rotation, and the extension of the work of the Solar Union to include research on the stars were taken up. Some recent results obtained by Professor Kapteyn on the subject of star streams and the parallax of stars with their relation to the results of Professor Campbell were also discussed.

In addition to attendance at the two meetings Mr. Plaskett visited the Lick and Lowell Observatories, the Ryerson Physical Laboratory at Chicago and the workshops of the Solar Observatory, and part of his address was devoted to the items of interest seen at these places. At the close of the address a considerable number of questions asked showed the interest aroused.

February 9, at the Observatory.—Dr. W. F. King gave a lecture on "Some Geometrical Problems Connected with Geodesy." Dr. King first gave a short historical account of the progress of our knowledge regarding the shape of the earth, discussing in

detail the latest theories bearing on the subject. Assuming the earth to be an oblate spheroid, he derived its most important geometrical properties, and illustrated the meaning of these by reference to the earth itself. He then explained how the ordinary formulæ for spherical trigonometry could not in general be applied to the oblate spheroid, without certain corrections. Dr. King then discussed the curves upon the surface of the earth most commonly met with in surveying operations, viz :— plane curves, curves of alignment and geodetic lines; showing their properties, how they are obtained on the surface of the earth, and their relative positions.

C. E.

AT HAMILTON

February 1, 1911.—The annual meeting of the Hamilton Centre was held this evening.

The election of officers resulted as follows :—

President, Wm. Bruce,

First Vice-President, E. H. Darling, 21 Stanley Ave.,

Second Vice-President, W. A. Robinson, 34 Charlton St., E.,

Secretary, T. H. Wingham, 174 Aberdeen Ave.,

Treasurer, Seneca Jones, 67 Ontario St.,

Council, Rev. R. E. M. Brady, 475 Mary St.,

Rev. J. J. Morton, 39 Park St., S.,

G. Parry Jenkins, 237 John St., S.

Mr. Alfred T. Bratton, 17½ King St., E., Hamilton, was elected a member of the Society.

The Secretary reported that nine meetings had been held since last annual meeting ; the average attendance being between 50 and 60, and that the membership stood at 74. The Treasurer's report (which has been forwarded to the General Treasurer) showed receipts of $155.03. Disbursements $76.50. Balance $78.53.

The lecture of the evening was entitled "Our World in Space," by Mr. J. R. Collins, of Toronto. After referring to our ideas of space and time, the lecturer explained how many of the problems connected with our earth are solved. These problems

refer to its form, a sphere flattened at the poles, the amount and cause of same; its weight and variation of attraction at various points of the earth; its density, rigidity, etc.; its motion on its axis, and about the sun and through space.

The lecture was illustrated by a number of slides, including many of great interest outside the matter of the lecture, especially a set of photographs of eminent astronomers.

A hearty vote of thanks was accorded the lecturer at the close.

February 24.—The lecture of the evening was by our new president of the Centre, Mr. William Bruce, and was entitled "A Voyage along the Ecliptic." In his pleasing imaginative way the president took the members of the Centre first on a trip around the earth, and then along the ecliptic. The various constellations with their chief stars, binary systems, clusters, and other notable features were described, causing many to desire to visit an observatory to see for themselves the beauties of the heavens thus described.

T. H. W.

At Peterborough

January 24, 1911.—Mr. Thomas Elliott, 112 McDonell St., Peterborough, was elected a member of the Society.

The Secretary gave a description of the new equatorial telescope that Mr. H. B. Collier, the president of the Centre has set up, illustrating his remarks with lantern slides. Mr. Collier has done himself and the Society credit by installing this excellent instrument. It is moved by clockwork. The hour circle reads to one minute of time and the declination circle to 5 minutes of arc.

It was reported that the Stratton and the Toronto telescopes were being faithfully used by the members.

Mr. Collier gave a very enjoyable lecture on "The Moon's Surface." It dealt with the prominent physical features of our satellite, its mountain ranges, extinct volcanoes and sea-beds. The lecture was highly appreciated.

February 7. — In the absence of the President Mr. T. A. S. Hay occupied the chair.

Mr. R. A. Logan, 14 Murray St., Peterborough, was elected a member of the Society.

Mr. J. R. Collins, of Toronto, the general secretary of the Society, gave an interesting lecture on "Our World in Space," referring to the physical features and the laws which govern it, showing that while our earth was small, amid the heavenly orbs that sweep through space, yet its place was as important as any in the sun's family.

The lecture was profusely illustrated by lantern slides shown by Mr. H. O. Fiske.

A hearty vote of thanks was tendered to the lecturer.

February 28. — The lecture of the evening was by Rev. Dr. Marsh, the subject being "The Planet Saturn." After defining the term "planet," information regarding the distance of Saturn from the sun, its orbit and also the reports of recent observations were given.

D. B. M.

NOTES FROM THE DOMINION OBSERVATORY

Astrophysics

The spectroscopic binary θ^2 Tauri has been under observation here for about 15 months and some 40 plates have been obtained and measured. On two of these plates traces of a second spectrum have appeared and consequently it is desirable to obtain more plates when separation of the components is possible. The velocity curve is similar to that of θ Aquilæ and the star has a period of about 140 days. The most interesting feature about this binary, however, is that it is one of the Taurus stream recently discussed by Professor Boss.* According to his computations it should have a radial velocity of +40·5 km. per second. The approximate radial velocity of the system, as determined from the preliminary velocity curve, is +40 km. per second, a very good agreement.

J. S. P.

* *Astronomical Journal*, No. 604.

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada

December, 1910

Temperature — The mean temperature of December was below normal over the greater part of the Dominion. The exceptions being the northern and southeastern districts of British Columbia, Southern Alberta, Southeastern Manitoba and the Gaspé Peninsula. The largest negative departures occurred in the Province of Ontario, where they ranged between 5 and 10°. East of the Rocky Mountains the most pronounced cold of the month occurred during the last week, when temperatures much below zero were recorded in most districts.

Precipitation — From British Columbia to Manitoba the amount of precipitation recorded during December was, with local exceptions in Alberta and Saskatchewan, in excess of the average, and in the Western Provinces the fall was generally heavy.

Precipitation was deficient, as a rule, from Ontario to the Maritime Provinces, but locally in the highlands of the former Province, and in northern districts further east the fall was in excess of the average.

January, 1911

Temperature — The temperature was above the average in Ontario, in the Georgian Bay districts and in the Lower Lake Region east to about the 77th meridian, the positive departure varying from 1 to 5 degrees. In the Maritime Provinces and the Eastern Townships of Quebec, also, it varied from average to 2

degrees above. In the greater part of Quebec and in Eastern Ontario it was from average to 2 degrees below, while from the Lake Superior district to our British Columbian Coast it was everywhere below the average, the negative departures from Manitoba to the interior of British Columbia being excessive, as follows: Kamloops, 15 degrees below average; Barkerville, 14 degrees below; Edmonton, 16 degrees below; Battleford, 15 degrees below; Calgary and Prince Albert, 13 degrees below; Swift Current and Qu'Appelle, 12 degrees below; Minnedosa, 11 degrees below.

Precipitation — In British Columbia the precipitation was above the average over the greater portion of the Province, the snowfall in Cariboo exceeding the usual quantity by some 32 inches. Throughout the Western Provinces, except in one or two isolated districts, the snowfall was above the average amount, the positive departure being locally pronounced, noticeably in Northern Alberta, Saskatchewan and parts of Manitoba. In Ontario and over Western Quebec the precipitation was deficient, being from one-third to less than a half the average quantity, except very locally in the Lake Superior district, where the snowfall appears to have been in excess of the normal amount. In Eastern Quebec the precipitation was a little above the average in some places and below in others, and in the Maritime Provinces everywhere below except in Cape Breton, the negative departure being very marked in New Brunswick.

Temperatures for December, 1910, and January, 1911

Station	December		January	
	Highest	Lowest	Highest	Lowest
Yukon				
Dawson	26	-48	0	60
British Columbia				
Atlin	38	24	40	42
Agassiz	55	27	48	3
Barkerville	38	0	38	-40
Kamloops	46	12	42	-32
New Westminster	50	24	44	6
Prince Rupert	58	24	44	4
Vancouver	53	28	44	6
Victoria	51	34	50	15
Western Provinces				
Battleford	38	24	32	-36
Broadview				
Calgary	53	-12	46	44
Carman				
Edmonton	49	20	42	52
Medicine Hat				
Minnedosa	33	-40	19	-43
Moose Jaw	32	-16	27	-40
Oakbank	33	-42	20	-45
Portage la Prairie	33	-35	25	-38
Prince Albert	40	-28	28	-50
Qu'Appelle	36	-20	31	-38
Regina	35	-22		
Swift Current	42	-16	34	-34
Winnipeg	34	-42	20	-37
Ontario				
Agincourt	37	16	42	-8
Aurora	36	-21	42	-16
Bancroft	33	-32	41	-26
Barrie			41	-13
Beatrice	37	23	43	21
Birnam	35	-7	43	0
Bloomfield	35	-20	42	13
Brantford	37	-14	45	-4
Bruce Mines	35	-22	39	-28
Chatham	37	2	49	0
Clinton	35	10	41	-12
Cottam	38	-6	49	3
East Toronto	35	-15	42	-7
Gravenhurst	37	-33	42	-24
Guelph	35	-5	42	-1
Haliburton	34	28	40	-25
Hamilton	39	6	44	0
Huntsville	34	31	45	-22
Kenora	24	-37	25	-37
Kinmount	34	-34	40	-28
Kingston	36	-12	40	-17
Lakefield	46	17	48	-11
London	36	-9	46	-8
Lucknow	33	-4	38	3
Madoc	35	-25	40	-13
Meaford				
Midland	40	-10	42	-12
North Gower				
Otoanbee	35	-10	40	-11
Ottawa	35	-25	40	-17
Owen Sound	38	12	52	0
Paris	41	-9	45	-1
Parry Sound	38	-23	43	-18
Peterboro'	36	-26	40	-15
Point Clark				
Port Arthur	35	-30	35	-30
Port Barwell	40	-2		
Port Dover	36	10	47	-3
Port Hope				
Port Stanley	37	-6	44	4
Ronville	34	-32	42	-22
Sarnia	36	5	43	2
Southampton	38	1	42	-2
Stonecliffe	40	-28	40	-25
Stony Creek	40	-10	46	7
Stratford				
Toronto	39	-7	44	-2
Uxbridge	36	-21	40	-12
Wallaceburg	36	-6	47	-4
Welland	38	-7	47	-4
White River	34	-38	34	-48
Quebec				
Brome	37	-23	44	-26
Father Point	38	10	41	-17
Montreal	36	16	43	-12
Quebec	36	-21	41	-20
Sherbrooke	39	-17	47	-20
Maritime Provinces				
Charlottetown	44	2	47	-14
Chatham	44	-6	46	-24
Dalhousie	39	-10	32	-10
Fredericton	46	15	48	-31
Halifax	48	3	52	-11
Moncton	49	-5	51	-20
St. John	48	3	47	-14
St. Stephen	49	20	50	-23
Sussex	49	14	50	-18
Sydney	51	7	54	-2
Yarmouth	48	8	50	0

Magnetic Observations

During the months of December and January no disturbances of magnitude were recorded, and on a large proportion of days the curves were normal. The only period of continued light disturbance was from January 24 to 31 when wavy motions were recorded extending to each side of the normal curve.

The following is an abstract of the data recorded at Agincourt.

Declination

Month	Mean of Month	Max.	Date	Min.	Date	Monthly Range	Amplitudes--Mean Daily	
							From hourly readings	From Means of Extremes
	° ′	° ′		° ′		° ′	′	′
Dec.	6 6·1	6 36·6	15	5 38·6	13	0 58·0	6·9	16·3
Jan.	6 6·6	6 26·3	26	5 42·6	10	0 43·7	6·7	17·8

Bifilar

	C.G.S. units							
Dec.	·16248	·16294	28	·16169	15	·00125	·00022	·00052
Jan.	·16243	·16278	2	·16166	25	·00112	·00023	·00053

Inclination

Month	Mean
	° ′
December	74 39·0
January	74 39·6

Earthquake Records by Milne's Seismograph

TORONTO

R. F. Stupart, Director.

P.T. = Preliminary Tremors. L.W. = Large Waves. Time is Greenwich Civil Mean Time, 0 or 24 h = midnight.

No.	Date 1910-11	P.T Comm h	P.T Comm m	L.W. Comm. h	L.W. Comm. m	Max. h	Max. m	End. h	End. m	Max. Amp. mm.	Durat. h	Durat. m	Remarks
973	Dec. 10	9	52·3) 56·3)			10	26·6	11?	48·0	0·5	1	55·7	LW. conspicuous for long duration
974	" 13	12?	16·0	12	35·5	12	46·5	14?	30·0	2·1	2	14·0?	Beg. & end'g mix'd up with air curr.
975	" 14	21	7·3?					21	25·8	0·2	0	18·5	Air c. going on
976	" 16	15	6·4			16	11·1	17	45·0?	1·0	2	38·6	Air c. at ending
977	" 21	10	35·3	10	39·9	10	49·3	11	17·4	0·5	0	42·1	" " " "
978	" 23	Air curr.		1	8·0	1	8·7	1	32·0	0·8			If any Pt's mixed up with air c.
979	" 30	1	19·6) 27·6)	Mixed up with air currents									
980	" 30	3	42·3	3	44·8	3	45·8	3	56·3	0·3	0	14·0	
981	" 30	9	48·1	Air currents									Slight thickening
982	Jan. 1	11	12·8?	11	19 8	11	23·9	11	36·5	0·2	0	23·7	Air c. at beginning
983	" 2	23	20·0) 48·0)			0	7·5	air c.					Thick'nings mix'd up with air. c.
984	" 3	23	27·6) 32·4)	2	23 49·2	0	27·4	2	57·8	7·0	3	25·4) 30·2)	Beg. doubtful air c. Turkestan earthquake
				B	0 9·5)								
				"	0 18·2)								
985	" 9	4	46·2?					4	49·2		0	3·0	Min. thickening
986	" 10	17	16·3					17	23·0		0	7·0	Doubtful as to being seismic thick.

Period 14 8 seconds 1 mm. = 0″·64.

VICTORIA, B. C.

E. B. Reed, Superintendent.

No.	Date 1909	P.T. Comm. h	P.T. Comm. m	L.W. Comm. h	L.W. Comm. m	Max. h	Max. m	End h	End m	Max. Amp. mm.	Durat. h	Durat. m	Remarks
999	Dec.? 10	9	39·9	9	50·0	10	10·9	12	10·9	1·0	2	31·0	{time LW's lasting a long
1000	" 13	12	0·0			13	2·2	14	37·2	1·4	2	37·2	Medium
1001	" 14	21	6·5					21	34·3	0·15	0	27·8	
1002	" 16	15	2·2	15	10·0	15	16·0	17	33·4	1·5	2	31·2	Well defined
1003	" 21	10	40·6?	10	57·8	11	9·3	11	25·4	0·15	0	44·8	
1004	" 23	0	48·9	0	57·0	1	0·4	1	24·4	0·9	0	35·5	
1005	" 30	1	11·3					1	35·4	0·05	0	24·1	
1006	" 30	3	42·8	3	43·4	3	45·1	3	56·1?	0·5	0	13·3	Ending mixed up with air c.
1007	1911 Jan. 1	11	12·5?	11	15·8	11	17·0	11	55·4	0·2	0	42·9	
1008	" 2	23	19·3?) 41·2)					0	21·2	0·05	1 0	01·9) 40·0)	Beginning doubtful
1009	" 3	23	38·6	23	48·7	24	19·4	2	55·9	9·0	3	17·3	Turkestan earthq.
1010	" 9	4	50·3					4	53·3	0·05	0	3·0	

Period 15 seconds 1 mm. = 0″·76

J. V.

ASTRONOMICAL NOTES

STAR STREAMS.—"KAPTEYN discovered six years ago that the stars have a preference for motion toward and from two opposite points of the celestial sphere: one of the points being in right ascension 93° and declination + 12°. His determination was based upon the observed proper motions of stars. A half dozen confirmations were promptly published by other astronomers, basing them also upon proper motion data. Our radial velocity determinations afforded an admirable test of Kapteyn's conclusion. If the stars are moving at random, the average velocities of approach and recession should be equal in all parts of the sky. If the stars have a preference for motion in the directions assigned by Kapteyn, the velocities of approach and recession should be greater in the vicinity of the two points defined by Kapteyn than in areas intermediate between these two points. I found that 154 stars lying within 30° of Kapteyn's points have an average radial velocity of 15·9 km. per second; that 383 stars lying in the zones 30° to 60° from these points have average radial velocities of 14·0 km. per second; and that 508 stars situated in the zones 60° to 90° from these points have average radial velocities of only 12·75 km. per second. It was therefore found that the average radial velocities near Kapteyn's points are approximately thirty-three per cent. greater than the average velocities of the stars situated midway between these two points. Kapteyn's conclusions were confirmed.

"The radial velocities of the stars permit us to determine the average distance of large classes of stars, though not of indi-

vidual stars. Computations to this end, while highly preliminary, led to interesting conclusions.

"The view had prevailed that early-type stars were further away from our position in space than are the older stars. Kapteyn's results, for example, placed the early-type stars approximately two and a quarter times as far away from us as the older-type stars. My results do not confirm this conclusion. It is found that the stars of different spectral types are in general thoroughly mixed.

"It was found that all classes of stars down to the fifth, and especially the brighter magnitudes, were further away than the formulæ for average distances had placed them; that is, that the scale of the sidereal universe is greater than had previously been supposed."—Prof. W. W. Campbell in *Publications of the Astronomical Society of the Pacific*, No. 134.

New Stars.—Nebulæ are generally exceedingly tenuous bodies of vast dimensions, so that the energy acquired by the sun falling into a nebula would add little to the mean proper motion of stars. The surface heating would be very gradual to commence with: hence the light would increase slowly, giving us a curve almost horizontal to commence with; whereas the light-curve of a nova is always almost vertical at its commencement. Thirty years ago I worked out the light-curve of bodies passing into nebulæ, and I found no point of correspondence with that of a nova; whereas the light-curve deduced from the third bodies produced by solar grazes and those of novæ are absolutely identical in every detail. A nova is a body possessing intense transitory brilliancy. At maximum it is thousands of times as bright as the sun. The theory of the third body suggest it is so because it is an explosion.—Professor Bickerton, *English Mechanic*, March 3, 1911. J. R. C.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries.

Query

Referring to the complaint of the Editor in the last number that there was a lack of queries, a member writes:—

I think this is very unfortunate for the amateur member, such as myself, who would find, were the privilege generally availed of, a great source of information and pleasure in having many a simple yet puzzling question answered. With your kind permission I will make a beginning, trusting other amateur members will avail themselves of this source of information.

In this same number, under the heading of "Predictions for January and February" I find the following item:

"During January the equation of time rapidly rises, changing from 3m 29s on January 1 to 13m 30s on January 31. This effect, taken with the fact that at the beginning of the year the days are lengthening slowly *causes the time of sunrise to appear stationary for ten days or more at the beginning of the year while the time of sunset gradually becomes later.*"

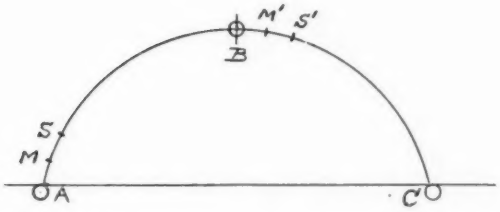
This is a most puzzling question to me, that while the lengthening of the period of light each day is distinctly noticeable in the evening, quite the reverse is the case in the morning. For after the shortest day in December the mornings *grow darker*, until well on to the end of January.

Avoiding technical terms as much as possible, will the Editor kindly explain this feature. -G. J. H.

Answer

This peculiar state of affairs arises from the fact that the time of sunrise and sunset given in our almanacs is given in *mean* time, not in *apparent* time.

In the figure let A represent sunrise and C sunset. Halfway between is B, and when the sun is there it is *apparent* noon, but not noon by the clock. It is noon as shown by a sun-dial.



Neglecting any change in the sun's declination during the day, the time from A to B is equal to that from B to C.

Now the apparent days (*i. e.* the intervals from apparent noon to apparent noon) are not all equal, and no time-piece can be constructed to correspond to apparent time. Hence an average or mean time is used. The *mean day* is the average of all the apparent days, and we call it noon when an imaginary point, which we may designate the *mean* sun, is on the meridian. This mean sun is usually a little before or a little after the real sun. In the almanac the difference between the two suns is called the Equation of Time. On January 1 it is $3^m\ 19^s$, additive to apparent time or subtractive from mean time, *i. e.* the *mean* sun is a little ahead of the *real* sun. Let it be represented by M in the figure.

If we work by standard time we must constantly add or subtract (as the case may be) from the mean time. Thus, in Toronto, standard time is $17^m\ 35^s$ faster than mean time. We might imagine a *standard sun* in the sky and that at standard noon it is on the meridian. In the figure S represents the standard sun.

Let us now consider the length of the day on January 1 at Toronto. From the declination of the sun (See HANDBOOK, p. 6) and the latitude of the place it is found by an application of trigonometry to be 9^h. Then the sun rose $4^h\ 30^m$ before and set $4^h\ 30^m$ after apparent noon. Hence we have,

Sunrise, $7^h\ 30^m$ a.m.
Sunset, $4^h\ 30^m$ p.m. } apparent time

To transform this to mean time, add $3^m\ 19^s$; hence we have

Sunrise, $7^h\ 33^m\ 19^s$)
Sunset, $4^h\ 33^m\ 19^s$) mean time

To bring this to standard time we add $17^m\ 35^s$, and thus obtain

Sunrise, $7^h\ 50^m\ 54^s$)
Sunset, $4^h\ 50^m\ 54^s$) standard time

Now try January 2. The length of the day is $9^h\ 1^m$. As before one half of this is morning and the other half afternoon, apparent time, and we have

Sunrise, $7^h\ 29^m\ 30^s$)
Sunset, $4^h\ 30^m\ 30^s$) apparent time

Adding the equation of time, $3^m\ 48^s$, to each we have

Sunrise, $7^h\ 33^m\ 18^s$)
Sunset, $4^h\ 34^m\ 18^s$) mean time

Again, adding $17^m\ 35^s$ to each we have

Sunrise, $7^h\ 50^m\ 53^s$)
Sunset, $4^h\ 51^m\ 53^s$) standard time

As a last example, take January 7. The length of the day is $9^h\ 6^m$, and the equation of time is $6^m\ 5^s$. Hence we have

Sunrise, $7^h\ 27^m$)
Sunset, $4^h\ 33^m$) apparent time

Sunrise, $7^h\ 33^m\ 5^s$)
Sunset, $4^h\ 39^m\ 5^s$) mean time

Sunrise, $7^h\ 50^m\ 40^s$)
Sunset, $4^h\ 56^m\ 40^s$) standard time

Thus we see that on these three days, according to our clock time, the time of sunrise is practically the same, while the time of sunset has changed about a minute per day.

It will be noticed that the sum of the equation of time and the correction for standard time has been subtracted from the forenoon and added to the afternoon, and hence the latter is much longer than the former.

Astronomical Society of India

In a letter to the Secretary, asking that it be placed on our exchange list, the President of the above Society gives some interesting information regarding it. Though only founded on July 26, 1910, the Society has 250 members. Its meetings are held monthly at Calcutta, and the proceedings are printed in a monthly journal known as *The Journal of the Astronomical Society of India*.

The Society is the first scientific body of its kind in India, and the speed with which members are joining shows that the country was ready for it. It has the highest official recognition, and a large number of Indian gentlemen are amongst its members.

The Royal Astronomical Society of Canada may well extend congratulations to a sister society in Greater Britain.

More Newspaper Astronomy

The following interesting account of a lecture by one of our worthy members appeared in an Ontario paper:

> The lecture was most enjoyable and proved to be very instructive to the members. It was one of a series given by the president, and was thoroughly enjoyed. All the stars in the heavenly realm were described. The group of Causon was described, and it was explained that if the telescope were used the group could be plainly seen. The cluster of stars in which Halley's comet was discovered was explained and also the cluster of Leo the Lion, which is regarded as the king of the sky, so far as beauty is concerned.

The Society's "Handbook"

The Editor is pleased to have the testimony of Mr. W. R. Ludewig, Secretary of the Astronomical Society of Pittsburgh, Pa., that he has found our "Handbook" of use. He remarks: "I might mention the little Handbook that I received from the Society in 1907; it was really the best little help to an amateur that I have ever seen, so if the Society has issued one for the present year a copy would certainly be greatly appreciated."

The Editor has in prospect many improvements for the issue for next year, which, it is intended, shall appear before the close of 1911.

The Vatican Observatory

An interesting account of this institution is given in a well-illustrated article in *Knowledge* for February. Though its foundation antedates that of the Royal Observatory at Greenwich by nearly one hundred years, it is only in modern times that it has become a power in astronomical research. The largest instrument is a 16-inch refractor, but in addition are the refractor engaged upon the Astrographic Chart, a photoheliograph, and others less important. The domes rest upon ancient fortifications erected in the ninth century. Indeed, there seems a wonderful combination of nature, science and art displayed throughout the observatory and its surroundings. There is also a curious mixture of the old and the new. Electric lights and electrically-driven domes are found on the bulwarks of long past centuries; in a large open-air den are two lions presented to the Pope by Emperor Menelik; while midway between the domes rises the slender spire of the chapel surmounting an exact replica of the famous grotto of Lourdes, with its bubbling spring of healing waters all complete!

The observatory is now under the competent direction of Father J. G. Hagen, formerly of Georgetown Observatory, Washington, D.C.

C. A. C.